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ABSTRACT

A phonetic study of vowel devoicing in the Shanghai dialect of Chinese explored the phonetic conditions under which the high, closed vowels and the apical vowel in Shanghai are most likely to become devoiced. The phonetic conditions may be segmental or suprasegmental. Segmentally, the study sought to determine whether a certain type of pre-vocalic consonant is more likely to cause the following vowel to devoice. Suprasegmentally, it sought to determine whether a certain tone category is more likely to cause the vowel to devoice. The study also investigated whether the position of the syllable in a polysyllabic compound constitutes a conditioning factor for a vowel to devoice, and whether the rate of speech has an effect on vowel devoicing. The speech of a male native speaker reading a word list with specific bisyllabic and polysyllabic compounds was subjected to spectrographic analysis. Results are analyzed and conclusions are drawn. Substantial appended material includes the lists of compounds, translations, tone patterns, and speech rates, a 16-item bibliography, and the spectrograms. (MSE)

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VOWEL DEVOICING IN SHANGHAI

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1. INTRODUCTION

It is well documented that high, closed vowels [i, u] devoice more frequently than low vowels (Greenberg 1966, Jaeger 1978). According to the Stanford Phonology Archive, there are at least 44 languages which have devoiced vowels. The Japanese vowel devoicing seems to have received most attention (Block 1950, Martin, 1952, Shitaba 1955, Kindaichi 1958, Han 1962a, 1962b, McCawley 1968, Sawashima 1969, 1971, Kawakami 1970, Hirose 1971, Ohso 1973, Lovins 1976, Beckman and Shoji 1983). In a detailed analysis of the Japanese phonemics, Block (1950) observes that in Japanese the high, close vowels [i, u] become devoiced when preceded and followed by voiceless consonants and for the non-high vowels the process of devoicing occurs in rapid speech only. Han (1962), using a sound spectrograph, investigates phonetic conditions for the high, closed vowels [i, u] to devoice in Japanese, and concludes that (1) the high, closed vowels [i, u] are more ready than other non-high vowels to devoice as they are inherently shorter than [e, a, o]; (2) [i, u] are more ready to devoice in rapid speech, (3) in a high-pitched syllable and in normal speech rate, vowels [i, u] do not devoice, (4) [i, u] devoice only when preceded and followed by voiceless consonants, (5) vowel devoicing is not likely to occur in two successive syllables. Thus, inherent vowel duration, speech rate, pitch, and consonant environment are determining factors for vowel devoicing. Ohala (1975) suggests that compared to an open vowel, a high, closed vowel, following a voiceless aspirated stop, causes (1) a greater oral pressure and thus a lower trans-glottal pressure, the effect of which is to inhibit voicing, and (2) increased oral air velocity, the effect of which is to produce greater frication. Thus, "high, closed vowels more frequently become devoiced and/or fricated than low, open vowels" (Ohala 1975 p.102). By measuring the lowest-frequency spectral prominences of the fricative [S] in the Japanese syllables [Si] (/si/) and [Su] (/syu/), Beckman and Shoji (1983) show that there is a spectral coloring of the fricative [S] by the following vowel. In the subsequent perceptual experiments of devoiced /si/ and /syu/, using both real speech and synthetic test tokens, they conclude that the Japanese subjects use the coloring of the fricative as a cue to identify the intended underlying vowel /i/ or /u/.

The present paper is a phonetic study of vowel devoicing in a tone language. The language under investigation is Shanghai, a Chinese dialect spoken mainly in the city of Shanghai. The paper explores the phonetic conditions under which the high, closed vowels [i, u] and the apical vowel [ɿ] in Shanghai are most likely to become devoiced. The phonetic conditions may be segmental as well as suprasegmental. Segmentally, the study seeks to determine whether a certain type of pre-vocalic consonant is more likely to cause the following vowel to devoice. Suprasegmentally, the study seeks to determine whether a certain tone category is more likely to cause the vowel to devoice. It also investigates whether the position of the syllable in a

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polysyllabic compound constitutes a conditioning factor for a vowel to devoice. It further investigates whether the rate of speech has an effect on vowel devoicing.

2. METHOD

In the Shanghai dialect, there are five citation tones, of which three [HL, MM, LM˄] ("˄" meaning "raised") occur on open, long monosyllables and two [M˄, LM] on checked, short monosyllables. However, in a bisyllabic or polysyllabic compound, each syllable receives a phonetic tone which may be high [H], mid [M], raised mid [M˄], raised low [L˄], low [L], or low-rising [R] (= [LM]). These phonetic tones constitute the tone patterns on the Shanghai compounds. There is a fixed number of phonetic tone patterns on the compounds and they are shown below:

Bisyllables	Trisyllables	Quadrisyllables
[H L]	[H M L]	[H M L˄ L]
[M M˄]	[M H L]	[M H M L]
[L M˄]	[L H L]	[L H M L]
[L R]	[L L R]	[L L L R]

(after Zee 1988; cf. Zee & Maddieson, 1980)

The test syllables used in the study are [sɻ] ("[ɻ]" being an apical vowel), [ʂi], [tsɻ], [tsʰɻ], [tɕi], [tɕʰi], [fu], and [hu]. Each syllable is a meaningful monosyllabic word and each may form meaningful compounds with other syllables. The corpus of data used for investigation includes bisyllabic, trisyllabic, and quadrisyllabic compounds as listed in Tables (I) - (V). Tables (I) and (II) show the bisyllabic, trisyllabic, and quadrisyllabic compounds which contain the test syllables [sɻ] and [ʂi], respectively. Tables (III), (IV) and (V) show the quadrisyllabic compounds which contain the test syllables [tsɻ] and [tsʰɻ], [tɕi] and [tɕʰi], and [fu] and [hu], respectively. Also shown in each table are the phonetic tone patterns on the compounds. The tone in square brackets is the phonetic tone realized on the test syllable, and "DEV" indicates that the vowel in the test syllable is devoiced.

The phonetic data was elicited from a male native Shanghai speaker who recently came from Shanghai to study at the Chinese University of Hong Kong. He is in his late twenties and has no history of speech or hearing difficulty. His speech was judged by other native Shanghai speakers also in their late twenties as standard metropolitan Shanghai spoken by the younger generation. The speaker read the word lists containing the compounds shown in Tables (I-V) at two different speech rates, normal and fast. One of the criteria for selecting the compounds was that they should be common and regularly used in everyday conversations. The recording was performed in a quiet room the recorded data were analysed, using a digital sound spectrograph (Kay 7800 Digital Sonagraph). Wide band spectrograms of each compound uttered in two speech rates, normal and fast, were made. Thus, a total of 228 spectrograms (114 compounds x 2 speech rates) was made.

3. RESULTS

The results of the spectrographic analysis of the compounds are shown also in Tables (I-V). Table I shows the result for the bisyllabic, trisyllabic and quadrisyllabic compounds which contain the test syllable [sɻ]. As shown, in all the bisyllabic compounds, there is only one case of vowel devoicing, indicated by "DEV", in which the apical vowel [ɻ] in the compound [$k^hEsɻ$] [HL] "boiled water" is devoiced. Notice, however, that (a) the devoicing occurs only in fast speech, (b) the syllable which contains the devoiced vowel receives a [L] tone, and (c) the vowel occurs in the compound-final position. Fig. (1) shows two wide-band spectrograms of the compound. The one on the left is the spectrogram of the the compound uttered at normal rate of speech and the one on the right is at fast speech rate. The duration of the compound at the normal rate of speech is approximately 0.472 sec. and in fast speech 0.379 sec. The temporal organizations of the compound uttered in two different speech rates are shown below:

[$k^hEsɻ$] [HL] "boiled water":

	Normal	Fast	Duration Reduced (%)
[$k^hEsɻ$]	0.472 sec.	0.379 sec.	19.7%
[k^hE]	0.308 sec.	0.267 sec.	13.7%
[sɻ]	0.267 sec.	0.236 sec.	11.6%
[s]	0.215 sec.	0.267 sec.	-24.2%
[ɻ]	0.082 sec.	0.000 sec.	100.0%

Interestingly, the duration of the frication of [s] in [sɻ] is increased in fast speech by approximately 24.2%. This would seem to be opposite to what is expected to occur since in fast speech the total duration of the compound and that of the test syllable [sɻ] are reduced by 19.7% and 11.6%, respectively. However, it merely implies that a final portion of the frication of [s] in fast speech is really the devoiced vowel segment. In Fig. (1) we can see that the voicing striations near the baseline immediately after the noise energy of [s] on the left (normal speech rate) disappear from the spectrogram on the right (fast speech rate). This indicates that the apical vowel [ɻ] in the test syllable is devoiced when uttered in fast speech. However, as shown in Table (I), the same vowel which receives a [H], [M] or [R] tone does not undergo the same devoicing process, even if it is uttered at fast speech rate and at the same time occurs in the compound-final position. The spectrograms of [sɻku] [MM̂] "fruit" (Fig. 2) show that the vowel [ɻ] in the same test syllable which occurs in the compound-initial position is not devoiced, as we can see the voicing striations of [ɻ] in the test syllable are present at both speech rates, and this is also true for [$k^hɔsɻ$] [MM̂] "examination" (Fig. 3). In both cases, the test syllable receives a [M] or [M̂] tone.

As for the trisyllabic compounds, there is a substantial increase in the number of the devoicing cases at both speech rates (Table (I)),

although the vowel in the test syllable which receives a [H] or [R] tone is still not devoiced under any conditions. However, there are devoicing cases associated with the test syllable which receives a [M] tone, and the vowel [ɻ̥] is devoiced at both speech rates if the test syllable is not in the compound-initial position. If, however, the test syllable occurs in the compound-initial position, as shown in the spectrograms of [sɻ̥kutʰE] [MHL] "fruit stalls" (Fig. 4), the vowel [ɻ̥] is not devoiced, irrespective of speech rate, although, as we can see, the spectrographic marking of the voicing striations of [ɻ̥] in fast speech is very much reduced.

In the case where the test syllable receives a [L] tone the apical vowel [ɻ̥] is devoiced at both speech rates only if the test syllable does not occur in the compound-initial position, as shown in the spectrograms of the compound [sɻ̥lEsɻ̥] [LHL] "tap water" (Fig. 5), whereas the same vowel in the compound-initial syllable is not, irrespective of speech rate. The temporal organizations of the compound uttered in two different rates of speech are shown below:

[sɻ̥lEsɻ̥] [LHL] "tap water":

	Normal	Fast	Duration Reduced (%)
[sɻ̥lEsɻ̥]	0.718 sec.	0.568 sec.	21.0%
[sɻ̥]	0.256 sec.	0.174 sec.	32.0%
[lE]	0.256 sec.	0.205 sec.	20.0%
[sɻ̥]	0.297 sec.	0.267 sec.	10.0%

The pattern of the devoicing of the apical vowel [ɻ̥] in the quadrisyllable compounds is similar to that in the trisyllabic compounds. Again, as in the case of the trisyllables, the vowel is not devoiced, irrespective of speech rate, if the test syllable receives a [H] or [R] tone. The vowel becomes devoiced at both speech rates, however, if the test syllable receives a [M] tone (or, a [L˗] tone) and does not occur in the compound-initial position, as shown in the spectrograms of the compound [tIkosɻ̥fɜ] [MHML] "square" (Fig. 6). The vowel is also devoiced at both speech rates if the test syllable receives a [L] tone and occurs either in the compound-final position, as shown in the spectrograms of [fEgasosɻ̥] [HML˗L] "ketchup" (Fig. 7), or penultimate position as in the case of the compound [sɔlosɻ̥tsi] "16th Century" which has a tone pattern of [LLLR]. The temporal organizations of the quadrisyllabic compound [fEgasosɻ̥] [HML˗L] "ketchup" uttered in two different speech rates are shown below. Interestingly, the duration of the syllable [ga] is almost unaffected when the compound is uttered in fast speech:

[fEgasosɻ̥] [HML˗L] "ketchup":

	Normal	Fast	Duration Reduced (%)
[fEgasosɻ̥]	0.743 sec.	0.625 sec.	15.9%
[fE]	0.195 sec.	0.164 sec.	16.0%
[ga]	0.108 sec.	0.103 sec.	0.04%
[so]	0.185 sec.	0.164 sec	11.4%
[sɻ̥]	0.267 sec.	0.215 sec.	19.5%

Here, it should be pointed out that in Shanghai the test syllable in the initial position of a compound which receives a phonetic tone pattern of [LR], [LLR], or [LLLR], is always a checked syllable, [CV?] (although the syllable-final glottal stop is deleted when it is followed by a segment of any type), which does not contain a high closed tense vowel, [i] or [u], or an apical vowel [ɿ]. Therefore, a syllable in this context does not constitute a test syllable.

Table (II) shows the vowel devoicing cases in the bisyllabic, trisyllabic, and quadrisyllabic compounds which contain the test syllable [ɕi]. Compared to the test syllable [sɿ] (Table (I)), we can see that in both normal and fast speech there is (a) no change in the number of devoicing cases associated with the bisyllabic compounds, (b) a substantial reduction with the trisyllabic compounds, and (c) a reduction of three cases associated with the quadrisyllabic compounds. The spectrograms of [ɕʏɕi] [HL] "fresh" (Fig. 8) show the only vowel devoicing case associated with the bisyllables. We can see the vowel is devoiced only when the compound is uttered in fast speech. As for the trisyllabic compounds, the vowel [i] is only devoiced at both speech rates if the test syllable occurs in a compound-final position and receives a [L] tone, and if the tone pattern on the compound is [HML]. Fig. 9 shows the spectrograms of the compound [ɕiõlEɕi̥] [HML] "kind of fierce", in which the vowel [i] is devoiced at both speech rates. However, if the tone pattern on the compound is other than [HML], then the vowel [i] is devoiced only in fast speech, as shown in the spectrograms of the compound [ɕiɔlEɕi] [MHL] "kind of small" (Fig. 10).

Compared to the trisyllabic compounds, there is an increase in the number of devoicing cases in the quadrisyllabic compounds which contain the test syllable [ɕi]. We can see that the vowel [i] is devoiced at both speech rates if the test syllable receives a [L] tone and occurs in the compound-final position, as shown in the spectrograms of [lɔkalEɕi̥] [LHML] "kind of boastful" (Fig. 11), or if the test syllable receives a [M] or [Lˆ] tone and occurs in a penultimate syllable, as shown in the spectrograms of the compound [sEtõɕikᵛo] [HMLˆL] "Shandong watermelons" (Fig. 12). The vowel is also devoiced in fast speech when it occurs in the penultimate syllable of a compound which has a tone pattern of [LLLR].

Comparing Table (I) with Table (II), we notice that in the trisyllabic compounds and quadrisyllabic compounds the apical vowel [ɿ] (Table II) is more devoiceable when preceded by an alveolar fricative [s] than the vowel [i] (Table II) when preceded by an alveolo-palatal fricative [ɕ]. We, however, will not be able to determine whether the vowel [i] is just as devoiceable if it is preceded by [s], or whether the apical vowel [ɿ] is less devoiceable if it is preceded by [ɕ], since in Shanghai the vowels [ɿ] in [sɿ] and [i] in [ɕi] occur in complementary distribution.

Table (III) shows the vowel devoicing cases in the quadrisyllabic compounds which contain the test syllables [tsɿ] or [tsʰɿ]. We can see that there are a greater number of devoicing cases associated with the test syllable [tsʰɿ] than with [tsɿ]. In fact, compared to all the other test syllables in the quadrisyllabic compounds (Tables, I,

II, IV, and V), the apical vowel [ɻ̩] when preceded by a voiceless aspirated alveolar affricate [tsʰ] has the highest devoiceablity (see also Table VI). Fig. (13) and Fig. (14) show the spectrograms of the compounds [ʈʂɤtsɻ̩tili] [HML^L] "in a gold shop" and [fɞ̃tsʰɻ̩tɑ̃tʂɪʔ] [HML^L] "satirical attack", respectively. We can see in both cases the apical vowel [ɻ̩] in the test syllable which occurs in the second position of the compound and receives a [M] tone is not devoiced at normal speech rate, however, the vowel becomes devoiced at fast speech rate only when it is preceded by an aspirated alveolor affricate [tsʰ]. Notice in Fig. (14) that the lax high front vowel [I] in the compound-final syllable [ʈʂIʔ] which receives a [L] tone is not devoiced at either speech rate. This seems to be contrary to what is expected, since its tense counterpart, [i], is almost always devoiced in the trisyllabic or quadrisyllabic compounds at both speech rates (Tables II, IV, and VI) when the test syllable receives a [L] tone and occurs in the compound-final position. It only indicates that the tense and lax high front vowels behave differently in the process of vowel devoicing. Notice in Table (III) that, in the quadrisyllabic compounds which contain the test syllable [tsʰɻ̩] and which have a rising tonal pattern of [LLLR], the vowel [ɻ̩] in the second, or penultimate syllable is devoiced at both speech rates. These in fact are the only cases where a vowel in the compound with such a tone pattern may become devoiced at both speech rates (cf. Tables I, II, IV & V). Fig. (15) shows the spectrograms of the compound [modʏtsʰɻ̩tɔ] [LLLR] "wooden bayonets". We can see that the vowel [ɻ̩] in the test syllable [tsʰɻ̩] which receives a [L] tone and which is in the penultimate position is devoiced at both speech rates.

Table (IV) shows the vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [ʈʂi] or [ʈʂʰi]. Similar to the test syllable [tsɻ̩] or [tsʰɻ̩] (Table (III)), there are more cases of devoicing of [i] when it is preceded by an aspirated alveolo-palatal affricate than when it is preceded by an unaspirated counterpart. Fig. (16) shows the spectrograms of the compound [ɐĪvə̃ʈʂitsɐ] [HML^L] "a news reporter", uttered at two speech rates. We can see the vowel [i] in [ʈʂi] which receives a [L^] tone is devoiced only in fast speech. However, as we can see in the spectrograms of the compound [sEsɻ̩ ʈʂʰi̥kʷʰE] [HML^L] "some three or four thousand dollars" (Fig. (17)) the vowel [i] in the penultimate syllable which receives the same [M] tone is devoiced at both speech rates.

Table (V) shows the vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [fu] or [hu]. We can see the number of vowel devoicing cases is greatly reduced, compared to the high front vowel [i] or apical vowel [ɻ̩] (Tables I, II, III, and IV). There are only five devoicing cases associated with the test syllable [fu] and four with the test syllable [hu], while in the case of [hu] the vowel [u] never undergoes vowel devoicing at the normal rate of speech. There are only two cases where the vowel [u] becomes devoiced at both rates of speech. In both cases, the devoiced [u] occurs in a compound-final syllable which receives a [L] tone. One of them is shown in the spectrograms of the compound [molʏkʰufu̥] [LHML] "Malinkov (a Russian name)" (Fig. (18)). Compared to the vowel [i], [u] or [ɻ̩] in the other test syllables, the vowel [u] in the test syllable [hu] is the only case where a vowel does not undergo vowel

devoicing when the test syllable occurs in compound-final position and at the same time receives a [L] tone. This is shown in the spectrograms of the compound [ɕiɔz̩lEhu] [MHML] "small matches" (Fig. (19). Since we have not used test syllables such as [su], [tsu], [tsʰu] or [fi] which are all meaningful monosyllables in the language, we at this time cannot be certain whether the high back vowel [u] is inherently more resistant to vowel devoicing, or whether the small number of devoicing cases is due to conditioning by the syllable-initial consonant type, [f] or [h]. Similarly, we are not certain whether the relatively greater number of devoicing cases of the high front vowel [i] is as a result of the vowel being inherently more devoiceable, or due to conditioning by the syllable-initial consonant, [ɕ], [tɕ], or [tɕʰ]. Thus, additional test syllables to verify this should be included in a future study.

The vowel devoicing cases in the Shanghai quadrisyllabic compounds are summarized in Table VI. The table shows the pattern of the distribution of devoicing cases. Based on Table VI, we reach the following generalizations with regard to the conditions under which a high closed vowel [i] or [u], or an apical vowel [ɻ̩] may undergo vowel devoicing in a quadrisyllabic compound in Shanghai:

(1) If the test syllable receives a [H] or [R] tone, then the high vowels, [i] and [u], and the apical vowel [ɻ̩], do not undergo vowel devoicing, irrespective of the rate of speech or the position of the test syllable in the compound.

(2) If the test syllable occurs in the compound-initial position, then the high vowels, [i] and [u], and apical vowel [ɻ̩] do not undergo the process of vowel devoicing, whether the test syllable receives a [H] or a [M] tone. This is also true for the vowels in the bisyllabic as well as trisyllabic compounds (Tables I & II). *(Notice that in our study the compound-initial [L] tone has not been studied systematically. The only tested cases where a [L] occurs on a compound-initial position are the trisyllabic compound, [sɻ̩lEsɻ̩] [LHL] "tap water" (Fig. 4; Table I) and quadrisyllabic compound, [sɻ̩bEtɕʰitsʰo] [LHML] "a private car" (Fig. 20; Table IV). In either case, the apical vowel in the compound-initial syllable which receives a [L] tone is not devoiced at either speech rate. We have yet to test the apical vowel as well as the high vowels [i] and [u], preceded by different types of consonant, in the same morphological and suprasegmental environments in order for any generalizations to be made.)*

(3) If the test syllable receives a [M] tone and occurs in the penultimate position of a quadrisyllabic compound which has a tone pattern of [M/LHML], then (i) the vowel [i] and apical vowel [ɻ̩] in [ɕi] and [tsʰɻ̩], respectively, are devoiced at both speech rates, (ii) the vowels [i], [u] and apical vowel [ɻ̩] in [tɕʰi], [hu] and [tsɻ̩], respectively, are devoiced only at fast speech rate, and (iii) the vowels [i] and [u] in [tɕi] and [fu], respectively, are not devoiced.

(4) If the test syllable receives a [M] tone and occurs in the second position of a quadrisyllabic compound which has a

tone pattern of [HML˚L], then (i) only the vowels [i] and [ɻ] in [ʈʂʰi] and [tsʰɻ], respectively, are devoiced, and then only at normal speech rate, and (ii) the vowels in other test syllables are not devoiced, irrespective of speech rate.

(5) If the test syllable receives a [L˚] tone and occurs in the penultimate position of a quadrisyllabic compound which has a tone pattern of [HML˚L] or [M/LHML], then (i) the vowel [i] in [ʂi] and [ʈʂhi] as well as vowel [ɻ] in [sɻ] and [tsʰɻ] are devoiced at both speech rates, and (ii) the vowels [i] in [ʈʂi], [ɻ] in[tsɻ], and [u] in [fu] and [hu] are also devoiced, but only at fast speech rate.

(6) If the test syllable receives a [L] tone and occurs in the second position of a quadrisyllabic compound which has a tone pattern of [LLLR], then (i) the high vowel [i] in [ʈʂʰi] is devoiced only at fast speech rate, (ii) the apical vowel in [tsʰɻ] is devoiced at both speech rates, and (iii) the vowels [i], [ɻ] and [u] in the rest of the test syllables are not devoiced. However, if the test syllable occurs in the penultimate position of a quadrisyllabic compound which has the same tone pattern, then (i) the apical vowel [ɻ] in [sɻ] and [tsʰɻ] is devoiced at both speech rates, (ii) the apical vowels [ɻ] in [tsɻ] and [i] in [ʂi] and [ʈʂʰi] are devoiced only at fast speech rate, and (iii) the vowel [u] in [fu] and [hu] as well as [i] in [ʈʂi] are not devoiced, irrespective of the speech rate.

4. CONCLUSION

To conclude, we have demonstrated with spectrographic evidence that (i) the process of devoicing of the high closed vowels [i] and [u] or apical vowel [ɻ] in the Shanghai dialect is subject to a number of phonetic conditioning factors: (a) the consonant type that precedes the vowel; (b) the phonetic tone on the test syllable in a compound; (c) the phonetic tone pattern on a compound; (d) the positioning of the test syllable in a compound, and (e) the rate of speech; (ii) the apical vowel [ɻ] has the highest devoiceability, followed by [i] and then [u]; however, it is not clear at this time whether [ɻ] is inherently the most devoiceable vowel or whether its high devoiceability is due to the consonant type that precedes it; (iii) the descending order of the devoiceablity of the different test syllables is: [tsʰɻ], [sɻ], [ʈʂʰi], [ʂi], [fu], and [hu]; (iv) a vowel occurring in a test syllable which receives a [L] tone is most likely to undergo devoicing process; (v) a vowel which is uttered in fast speech is more likely to undergo the process of devoicing; (vi) if a vowel is devoiced at normal speech rate it must also be devoiced at fast speech rate while the reverse is not true; (vii) there is a tendency for a vowel to become more devoiceable as the number of the syllable increases in a compound; (viii) the *Optimal Condition* for a vowel to become devoiced is when the test syllable occurs in the compound-final position and at the same time receives a [L] tone; and (ix) the *Least Favorable Conditions* for a vowel to become devoiced are (a) when the test syllable receives a [H] or [R] tone, and (b) when the test syllable occurs in the compound-initial position, irrespective of the tone it receives.

[End]

COMPOUND			TONE PATTERN	SPEECH RATE NORMAL	FAST
Bisyllables containing [s̩]:					
[sl̩ti]	[書]店	"a bookstore"	(H)L		
[kʰɔsl̩]	考[試]	"examination"	M(M̂)		
[sl̩ku]	[水]果	"fruit"	(H)M̂		
[kʰEsl̩]	開[水]	"boiled water"	H(L)		DEV
[səsl̩]	十[四]	"fourteen"	L(R)		
Trisyllables containing [s̩]:					
[slsə̃tsl̩]	[私]生子	"an illegitimate child"	(H)ML		
[jisl̩pɔ]	童[世]寶	"an immatured person"	M(H)L		
[slkutʰE]	[水]果攤	"fruit stalls"	(H)HL		
[ɕɪ̈sl̩ka]	新[世]界	"a new world"	H(H)L	DEV	DEV
[kɔŋzə̃sl̩]	工程[司]	"an engineer"	HM(L)	DEV	DEV
[sllEsl̩]	自來[水]	"tap water"	LH(L)	DEV	DEV
[məsl̩pi?]	墨[水]筆	"an ink pen"	L(L)R	DEV	DEV
[lomə̃sl̩]	綠墨[水]	"green ink"	LL(R)		
Quadrisyllables containing [s̩]:					
[sl̩tsl̩və̃di]	[師]資問題	"issue of teacher's quality"	(H)ML̂L		
[kɔsl̩ɔisə̃]	教[書]先生	"a teacher"	M(H)ML		
[sl̩tɕʰitukʷʰE]	[四]千多塊	"some 4,000 dollars"	(H)HML		
[tɪkɔsl̩fə̃]	的角[四]方	"square"	MH(H)L	DEV	DEV
[ɕiɕl̩kɔ̃ŋsl̩]	先[施]公司	"Xianshi Dept Store"	H(H)LˆL	DEV	DEV
[ɕɪ̈wɔ̃sl̩ti˚]	新華[書]店	"Xinhua Bookstore"	HM(Lˆ)L	DEV	DEV
[fEgɑsɔsl̩]	番茄沙[司]	"ketchup"	HMLˆ(L)	DEV	DEV
[həsEwɔsl̩]	瞎三話[四]	"talking nonsense"	MHM(L)	DEV	DEV
[lɪsl̩pɪtə̈i]	歷[史]筆記	"history notes"	L(L)LR		
[səlɔsl̩tə̈i]	十六[世]紀	"16th Century"	LL(L)R	DEV	DEV
[mɔdvlusl̩]	木頭螺[絲]	"a wood screw"	LLL(R)		

Table I. Vowel devoicing cases in the bisyllabic, trisyllabic and quadrisyllabic compounds which contain the test syllable [s̩].

COMPOUND			TONE PATTERN	SPEECH RATE NORMAL	FAST
Bisyllables containing [ɐi]:					
[ɐikʷo]	[西]瓜	"a watermelon"	[H]L		
[tsɭɐi]	仔[細]	"meticulous"	M[M˰]		
[ɐipɔ]	[細]胞	"cells"	[M]M˰		
[ɕʔɐi]	新[鮮]	"fresh"	H[L]		DEV
[sɐɐi]	直[線]	"a straight line"	L[R]		
Trisyllables containing [ɐi]:					
[ɐipofoŋ]	[西]北風	"vestnorthly wind"	[H]ML		
[sɔɐisǎ]	趙[先]生	"Mr. Zhao"	M[H]L		
[ɐikʷʰalə]	[死]快了	"to die soon"	[M]HL		
[tsvɐisǎ]	周[先]生	"Mr. Zhou"	H[M]L		
[ɐioŋlEɐi]	凶來[西]	"kind of fierce"	HM[L]	DEV	DEV
[ɐiɔlEɐi˰]	小來[西]	"kind of small"	MH[L]		DEV
[məɐiku]	墨[西]哥	"Mexico"	L[L]R		
[polEɐi]	薄來[西]	"kind of thin"	LL[R]		
Quadrisyllables containing [ɐi]:					
[ɐipəlijia]	[西]伯利亞	"Siberia"	[H]ML˄L		
[pɔɐikoŋəl]	保[險]公司	"an insurance company"	M[H]ML		
[ɐibitʰəli]	[嘴]皮場臉	"frivolous"	[M]HML		
[pǎβuɐikʷo]	澎湖[西]瓜	"Penghu watermelons"	MH[M]L	DEV	DEV
[ɐʔɐilÊɐi]	新[鮮]來西	"kind of fresh"	H[M]L˄L		
[sEtõɐikʷo]	山東[西]瓜	"Shandong watermelons"	HM[L˄]L	DEV	DEV
[ɐʔtɐʰilEɐi]	腥氣來[西]	"kind of fishy"	HML˄[L]	DEV	DEV
[lɔkalEɐi]˰	老茄來[西]	"kind of boastful"	MHM[L]	DEV	DEV
[məɐikuniŋ]	墨[西]哥人	"Mexican people"	L[L]LR		
[səpõɐikʷo]	日本[西]瓜	"Japanese watermelons"	LL[L]R		DEV
[monĩdvɐi]	木人頭[戲]	"a puppet show"	LLL[R]		

Table II. Vowel devoicing cases in the bisyllabic, trisyllabic and quadrisyllabic compounds which contain the test syllable [ɐi].

COMPOUND			TONE PATTERN	SPEECH RATE NORMAL	SPEECH RATE FAST
Quadrisyllables containing [ts̩]:					
[tsɨtsʰEtɕiatɕi:ʔ]	[資]産階級	"capitalists"	DO HL˄L		
[tɕʰi:tsɨpatɕaʔ]	七[嘴]八搭	"talkative"	N DO HL		
[tsɨsvwatɕiɛʔ]	[指]手劃腳	"gesticulating"	DO HML		
[ɛiɔsvtsɨkʰaʔ]	小手[指]甲	"pinkie nail"	MH DO L		DEV
[tɕɪʔtsɨtili]	金[子]店裡	"in a gold shop"	H DO L˄L		
[tɕɪʔɲʔtsɨpɔ]	金鐲[珠]寶	"jewelry"	HM (L˄) L		DEV
[tsɨsɐvɜ̃tsɨ]	知識份[子]	"intellectuals"	HML˄ (L)	DEV	DEV
[jɪtʰakʷɐtsɨ]	一場剎[子]	"all there is"	MHM (L)	DEV	DEV
[ɲɐtsɨkEdv]	盒[子]蓋頭	"a box cover"	L (L) LR		
[sɐpɜ̃tsɨtsʰE]	日本[紫]菜	"Japanese sea weed"	LL (L) R		DEV
[mɔvkotsɨ]	木而覺[知]	"insensible"	LLL (R)		
Quadrisyllables containing [tsʰ̩]:					
[tsʰ̩lɔdɜivtsʰ̩]	[吹]毛求疵	"critical"	DO HL˄L		
[tɕitsʰ̩sEfE]	幾[次]三番	"repeatedly"	N DO HL		
[tsʰ̩lɐukEli]	[廁]所間裡	"in the toilet"	DO HML		
[ɲɐfɔ̃gtsʰ̩lkʷɐʔ]	寒風[刺]骨	"icy wind"	LH DO L	DEV	DEV
[fɔ̃tsʰ̩tɜ̃tɕi:ʔ]	諷[刺]打擊	"satirical attack"	H DO L˄L		DEV
[ɕʔvɜ̃tsʰ̩tsE]	新聞[處]長	"a news director"	HM (L˄) L	DEV	DEV
[sEpɐtutsʰ̩]	三佰多[次]	"some 300 times"	HML˄ (L)	DEV	DEV
[sɨpɐtutsʰ̩]	四佰多[次]	"some 400 times"	MHM (L)	DEV	DEV
[ɐɐtsʰ̩pɐtsʰ̩]	十[次]八次	"8 or 10 times"	L (L) LR	DEV	DEV
[mɔdvtsʰ̩tɔ]	木頭[刺]刀	"a wooden bayonet"	LL (L) R	DEV	DEV
[lɔzɐtutsʰ̩]	六十三[次]	"63 times"	LLL (R)		

Table III. Vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [ts̩] or [tsʰ̩].

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COMPOUND			TONE PATTERN	SPEECH RATE NORMAL	FAST
Quadrisyllables containing [tɕi]:					
[tɕitʂʰikoŋsɻ]	[機]器公司	"a machine company"	(H) ML^L		
[ɕiɔtɕitɕiɛtsɔ]	小[雞]腳爪	"a small chicken claw"	M (H) ML		
[tɕitElEɕi]	[簡]單來西	"simple"	(H) HML		
[slzɛtɕitʰɑ̃]	四十[幾]趟	"some 40 times"	MH (H) L		
[fitɕikoŋsɻ]	飛[機]公司	"an airplane company"	H (H) L^L		
[ɑIvɑ̃tɕitsə̂]	新聞[記]者	"a reporter"	HM (L^) L		DEV
[tɕʰifɑ̃pɛtɕi]	千方百[計]	"trying every way"	HML^ (L)	DEV	DEV
[ɕiɔtsɔɕiɑ̃t ̬i]	小照相[機]	"a small camera"	MHM (L)	DEV	DEV
[sɛtɕibutsɻ]	日[記]簿子	"a diary"	L (L) LR		
[lozɛtɕitʰɑ̃]	六十[幾]趟	"some 60 times"	LL (L) R		
[lozɛlotɕi]	六十六[幾]	"sixty six times"	LLL (R)		
Quadrisyllables containing [tɕʰi]:					
[tɕʰifɑ̃pɛtɕi]	[千]方百計	"trying every way"	(H) ML^L		
[sltɕʰitukʷʰE]	四[千]多塊	"some 4,000 $"	M (H) ML		
[tɕʰitsʰokoŋsɻ]	[汽]車公司	"a car company"	(H) HML		
[slbEtɕʰitsʰo]	自備[汽]車	"a private car"	LH (H) L		DEV
[sÊtɕʰitukʷʰE]	三[千]多塊	"some 3,000 $"	H (H) L^L		DEV
[sEsl̥tɕʰi̥kʷʰE]	三四[千]塊	"some 3 - 4,000 $"	HM (L^) L	DEV	DEV
[pɔ̃lEpɔ̃tɕʰi̥]	奔來奔[去]	"running around"	HML^ (L)	DEV	DEV
[ɕijiɑ̃kʷatɕʰi̥]	死樣怪[氣]	"spiritless"	MHM (L)	DEV	DEV
[lotɕʰitukʷʰE]	六[千]多塊	"some 6,000 dollars"	L (L) LR		DEV
[sɑpɔ̃tɕʰitsʰo]	日本[汽]車	"Japanese cars"	LL (L) R		DEV
[tɑlEdɑtɕʰi]	踏來踏[去]	"stepping around"	LLL (R)		

Table IV. Vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [tɕi] or [tɕʰi].

COMPOUND			TONE PATTERN	SPEECH RATE NORMAL	SPEECH RATE FAST
Quadrisyllables containing [fu]:					
[futɕʰiliɛ̃nɻŋ]	[夫]妻兩人	"husband & wife"	(H)ML^L		
[tsəfutɕɣli]	正[副]經理	"manager & assistant manager"	M(H)ML		
[futɕɣlisə?]	[副]經理室	"assistant manager's office"	(M)HML		
[fəjiɘfukʰE]	文學[副]刊	"literary supplements"	MH(M)L		
[tsvfutɕɣli]	周[副]經理	"Assist. Manager Chow"	H(M)L^L		
[ɕɣvəfukʰE]	新聞[副]刊	"news supplements"	HM(L^)L		DEV
[sElətsʰofu]	三輪車[夫]	"a 3-wheeled cab rickshaw driver"	HML^(L)	DEV	DEV
[molɣkʰufu]	馬林可[夫]	"Malinkov"	LHM(L)	DEV	DEV
[lofusvtʰɔ]	六[副]手套	"six pairs of gloves"	L(L)LR		
[lotsəfudv]	六隻[斧]頭	"six axes"	LL(L)R		
[molotʰofu]	莫洛托[夫]	"Molotov"	LLL(R)		
Quadrisyllables containing [hu]:					
[hutʰihEdi]	[呼]天喊地	"yelling"	(H)ML^L		
[kohukoŋsl]	國[貨]公司	"a Chinese product store"	M(H)ML		
[hutʰihudi]	[火]天火地	"fire everywhere"	(M)HML		
[ŋakohutʰE]	外國[火]腿	"foreign ham"	LH(M)L		DEV
[tʰoŋhubətsə]	通[貨]膨脹	"inflation"	H(M)L^L		
[tɕ?wohutʰE]	金華[火]腿	"Jing-Hua ham"	HM(L^)L		DEV
[fitsvlɔhu]	非洲老[虎]	"African tigers"	HML^(L)		DEV
[ɕiɔsllEhu]	小自來[火]	"little matches"	MHM(L)		DEV
[səhutili]	雜[貨]店裡	"in a grocery store"	L(L)LR		
[sətɕ?huthE]	十斤[火]炭	"10 kettles of charcoal"	LL(L)R		
[modvlɔhu]	木頭老[虎]	"a wooden tiger"	LLL(R)		

Table V. Vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [fu] or [hu].

Tone Pattern on Quadrisyllables	[sɻ]		[tsɻ]		[ts^{h}ɻ]		[ɕi]		[tɕi]		[tɕ^{h}i]		[fu]		[hu]	
	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F
[H] M L$^{\wedge}$ L																
M [H] M L																
[M] H M L																
M/L H [M] L	D	D		D	D	D	D	D				D				D
H [M] L$^{\wedge}$ L	D	D				D						D				
H M [L$^{\wedge}$]L	D	D		D	D	D	D	D		D	D	D		D		D
H M L$^{\wedge}$[L]	D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
M/L H M [L]	D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
L [L] L R					D	D						D				
L L [L] R	D	D		D	D	D		D				D				
L L L [R]																

Table VI. Vowel devoicing cases in the quadrisyllabic compounds which contain the test syllable [sɻ], [tsɻ], [ts^{h}ɻ], [ɕi], [tɕi], [tɕ^{h}i], [fu] or [hu] (H = high tone; M = mid tone; L$^{\wedge}$ = raised low tone; L = low tone; R = LM rising tone; N = normal speech rate; F = fast speech rate; D = vowel devoiced)

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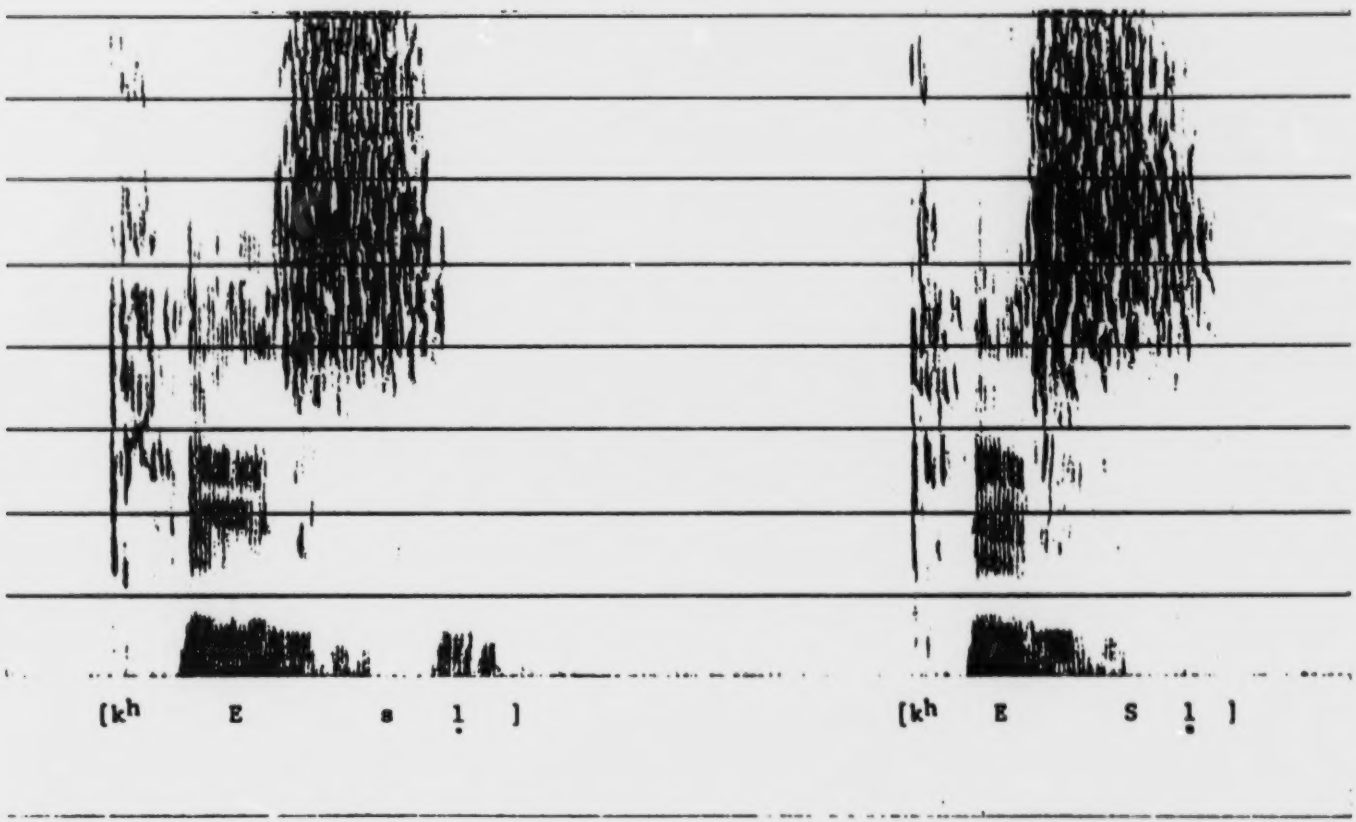

Fig.(1) Spectrograms of the bisyllabic compound [kʰEsl̩][HL]"boiled water" uttered at normal (left) and fast (right) speech rates.

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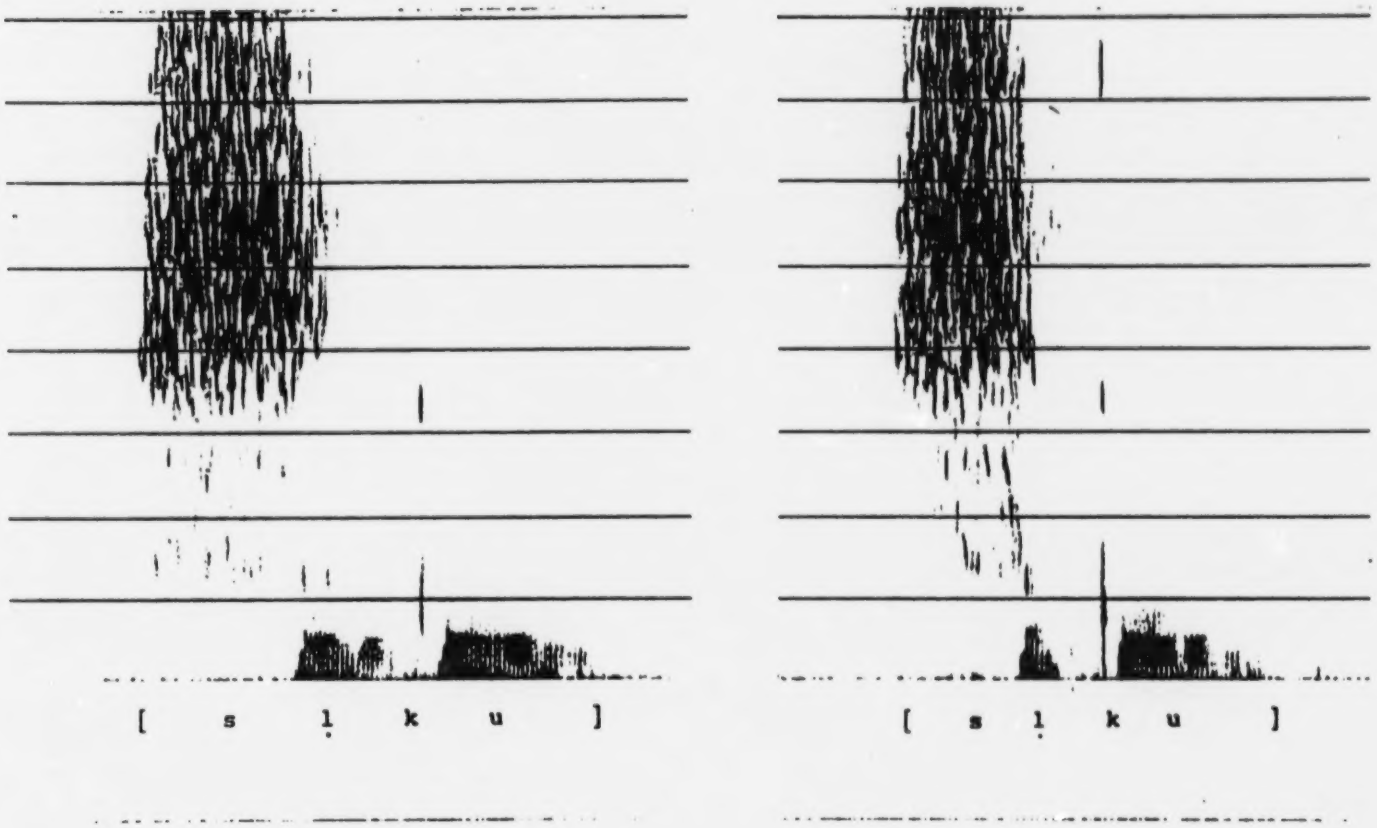

Fig.(2) Spectrograms of the bisyllabic compound [sl̥ku][MM^]"fruit" uttered at normal (left) and fast (right) speech rates.

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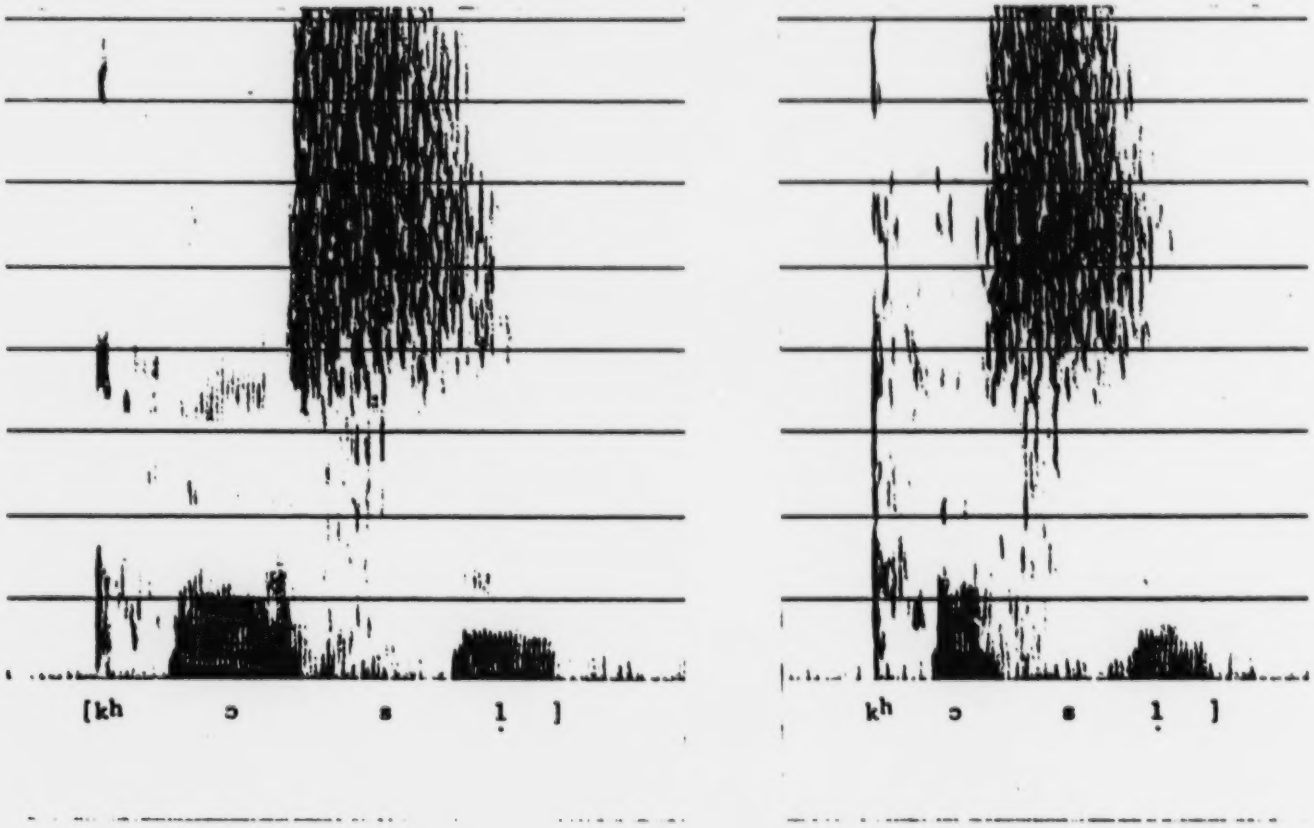

Fig.(3) Spectrograms of the bisyllabic compound [k^hɔsl][MM^]"examination" uttered at normal (left) and fast (right) speech rates.

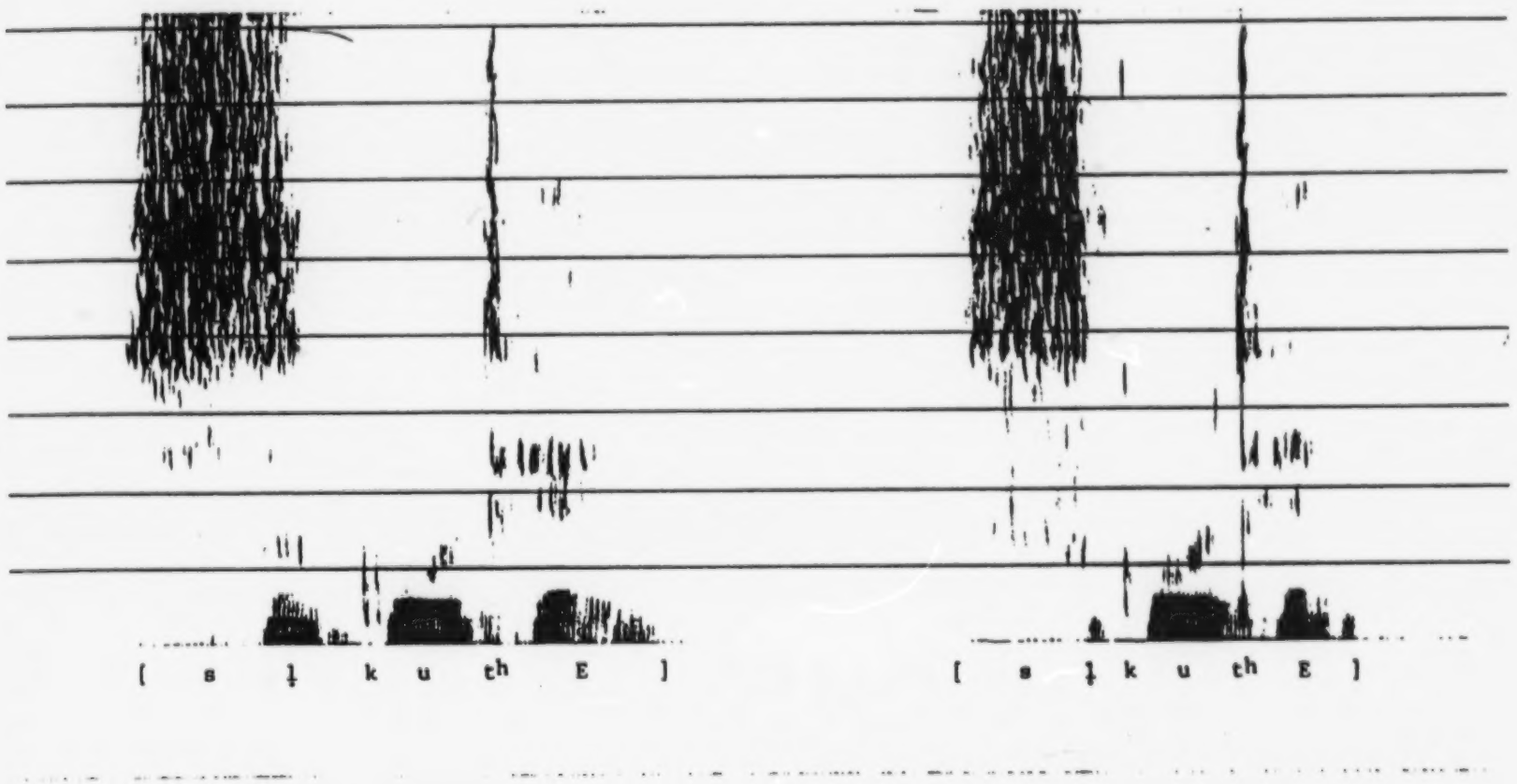

Fig.(4) Spectrograms of the tirsyllabic compound [sɻkut^{h}E][MHL]"fruit stalls" uttered at normal (left) and fast (right) speech rates.

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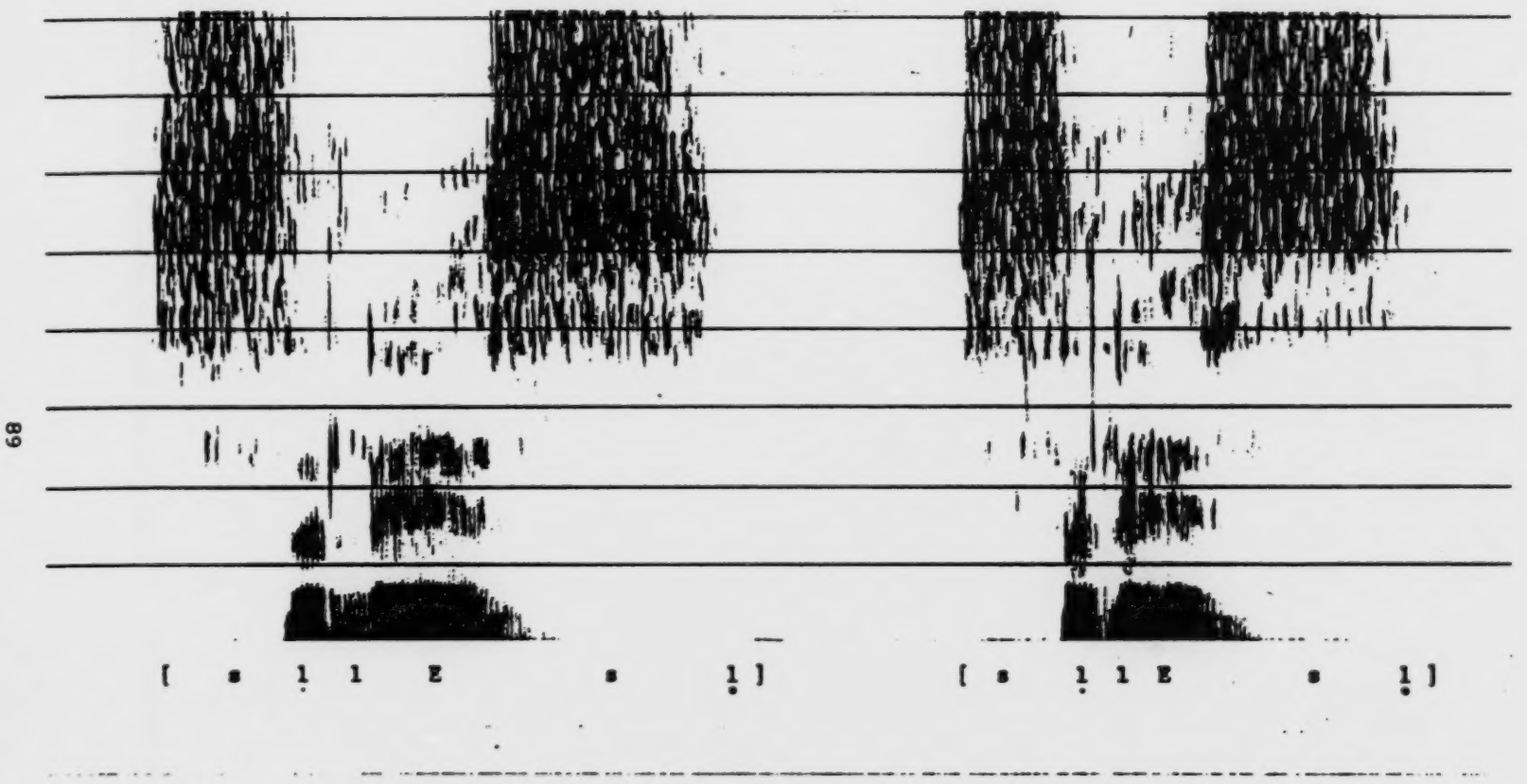

Fig.(5) Spectrograms of the trisyllabic compound [sl̩lEsl̩][LHL]"tap water" uttered at normal (left) and fast (right) speech rates.

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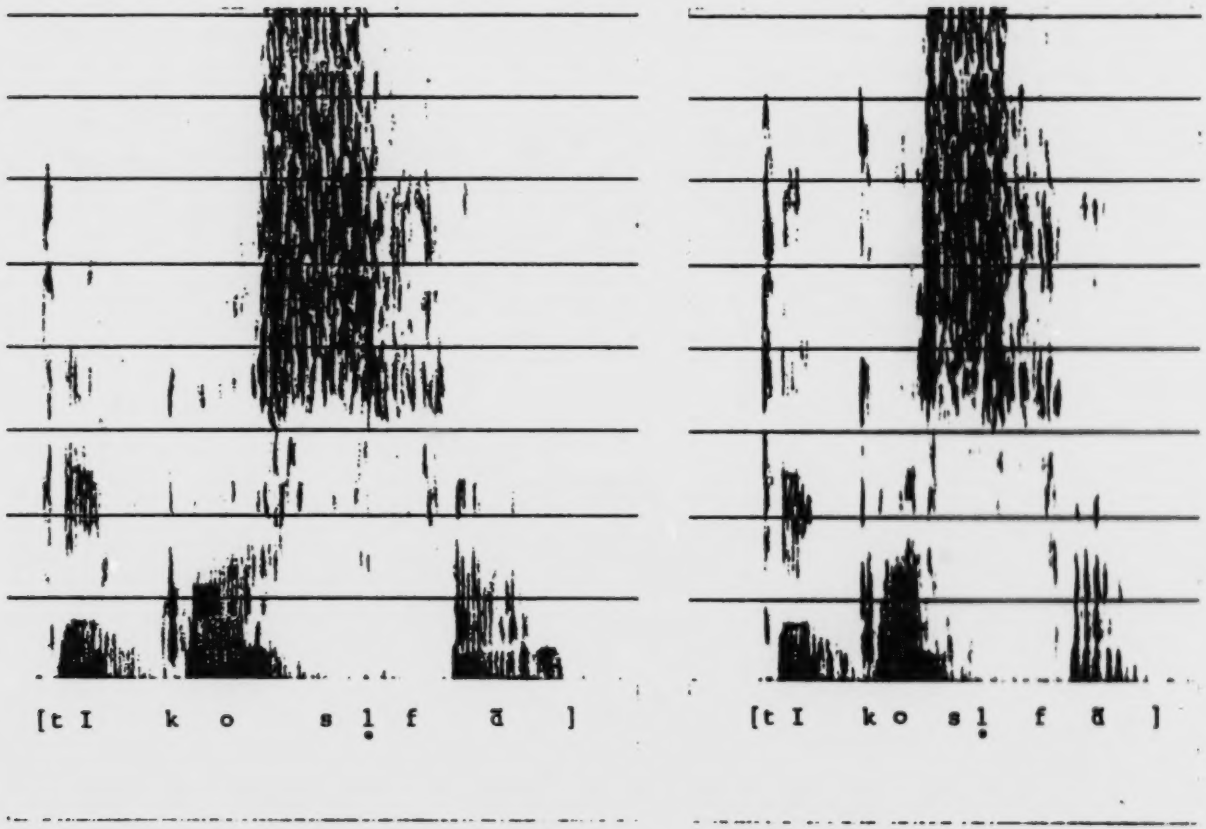

Fig.(6) Spectrograms of the quadrisyllabic compound [tIkoslfɑ][MHML]"square" uttered at normal (left) and fast (right) speech rates.

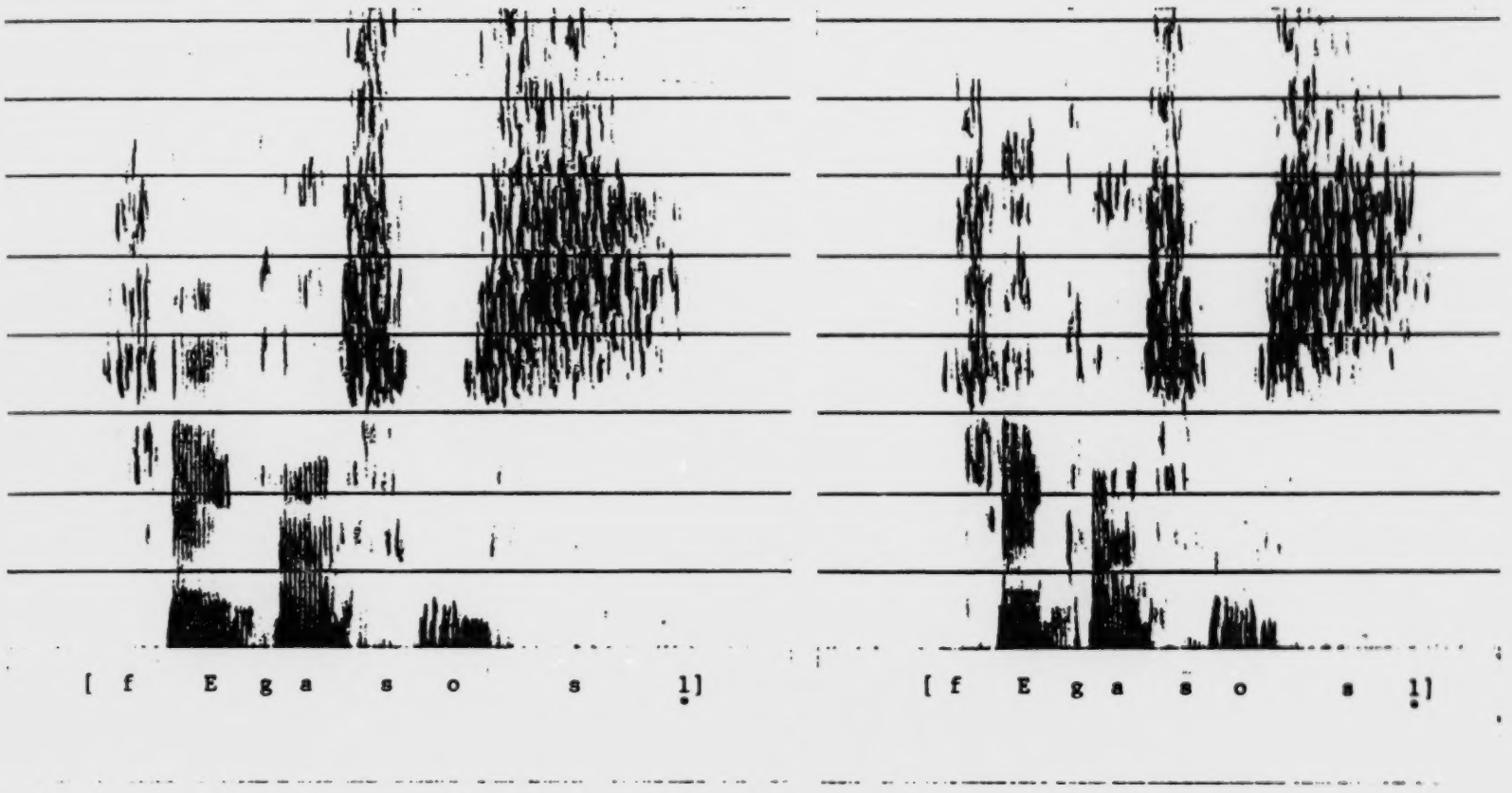

Fig.(7) Spectrograms of the quadrisyllabic compound [fEgasosl̥][HML^L]"tomato sauce" uttered at normal (left) and fast (right) speech rates.

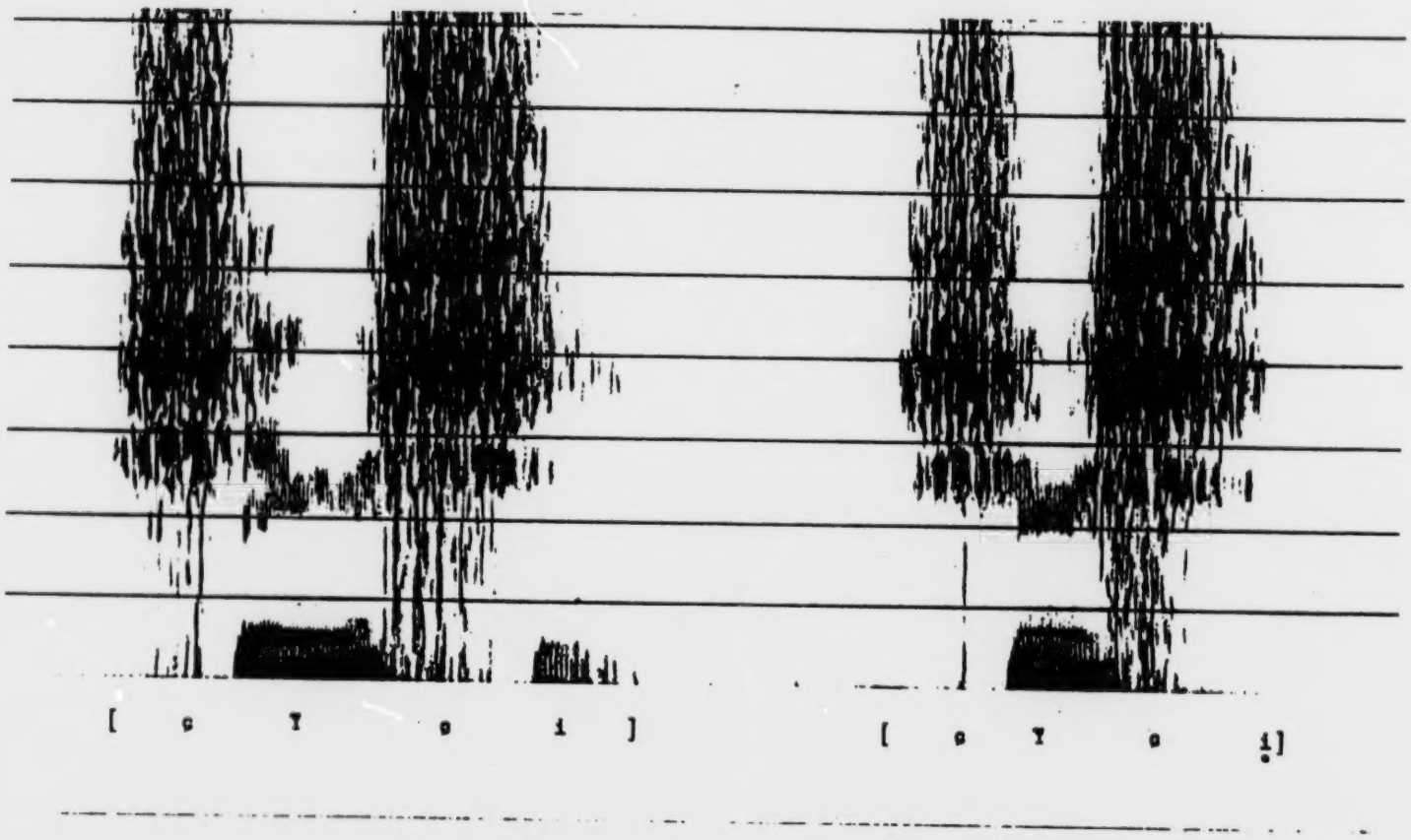

Fig.(8) Spectrograms of the bisyllabic compound [ɕʔɐi][HL]"fresh" uttered at normal (left) and fast (right) speech rates.

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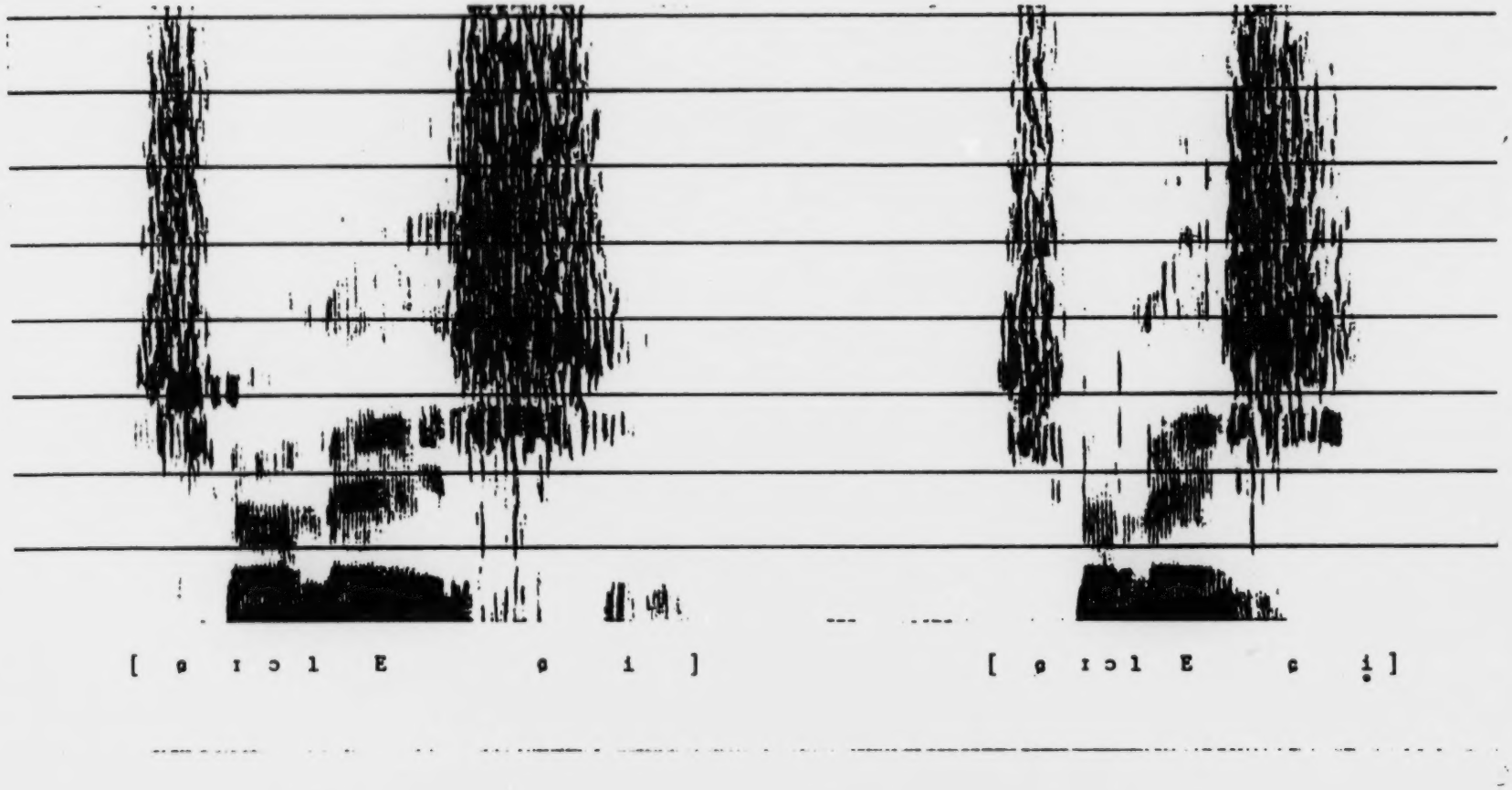

Fig.(10) Spectrograms of the trisyllabic compound [øɪɔlEøi][MHL] "kind of small" uttered at normal (left) and fast (right) speech rates.

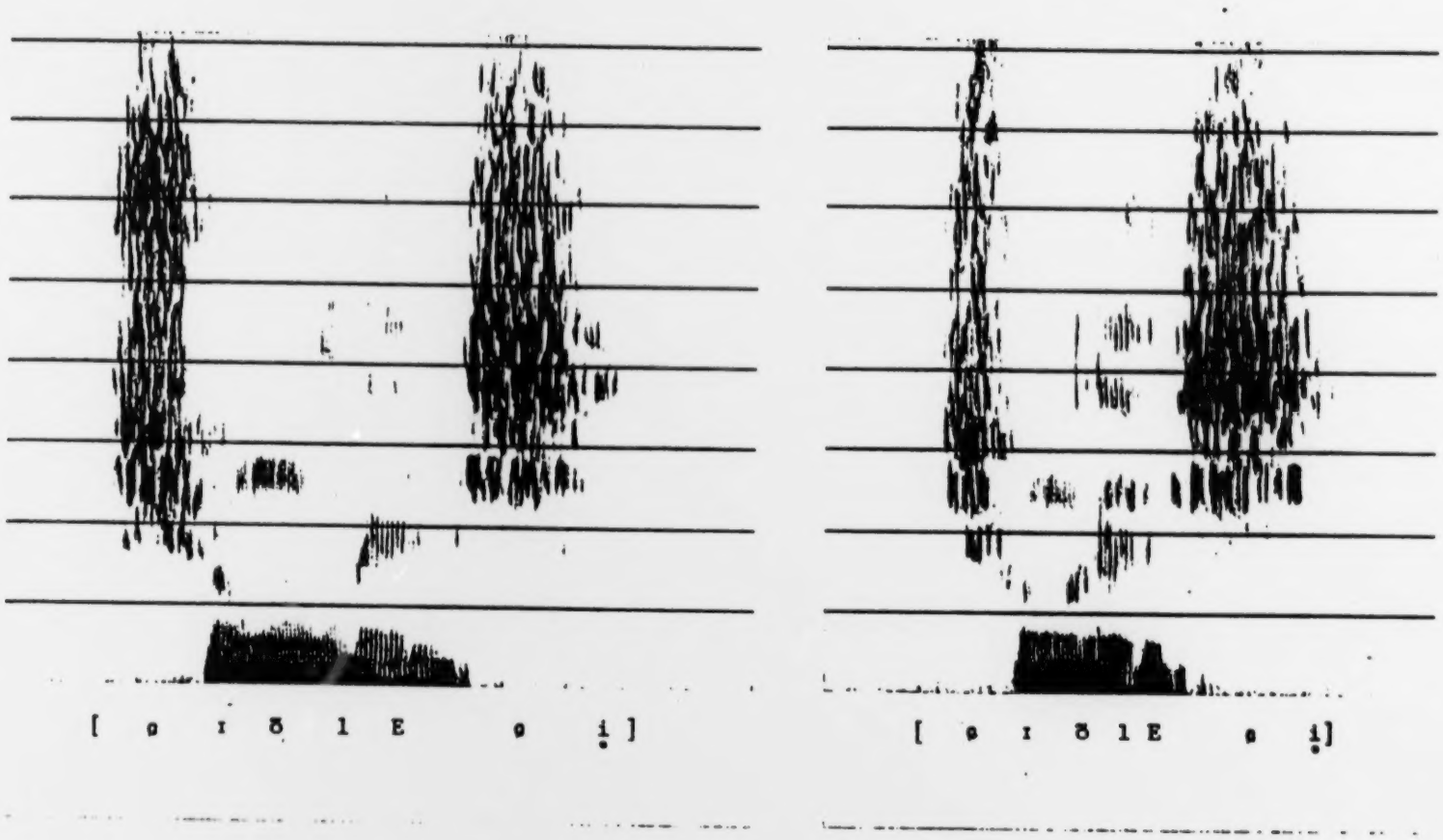

Fig.(9) Spectrograms of the trisyllabic compound [ɒɪðlEɒi̤][HML]"kind of fierce" uttered at normal (left) and fast (right) speech rates.

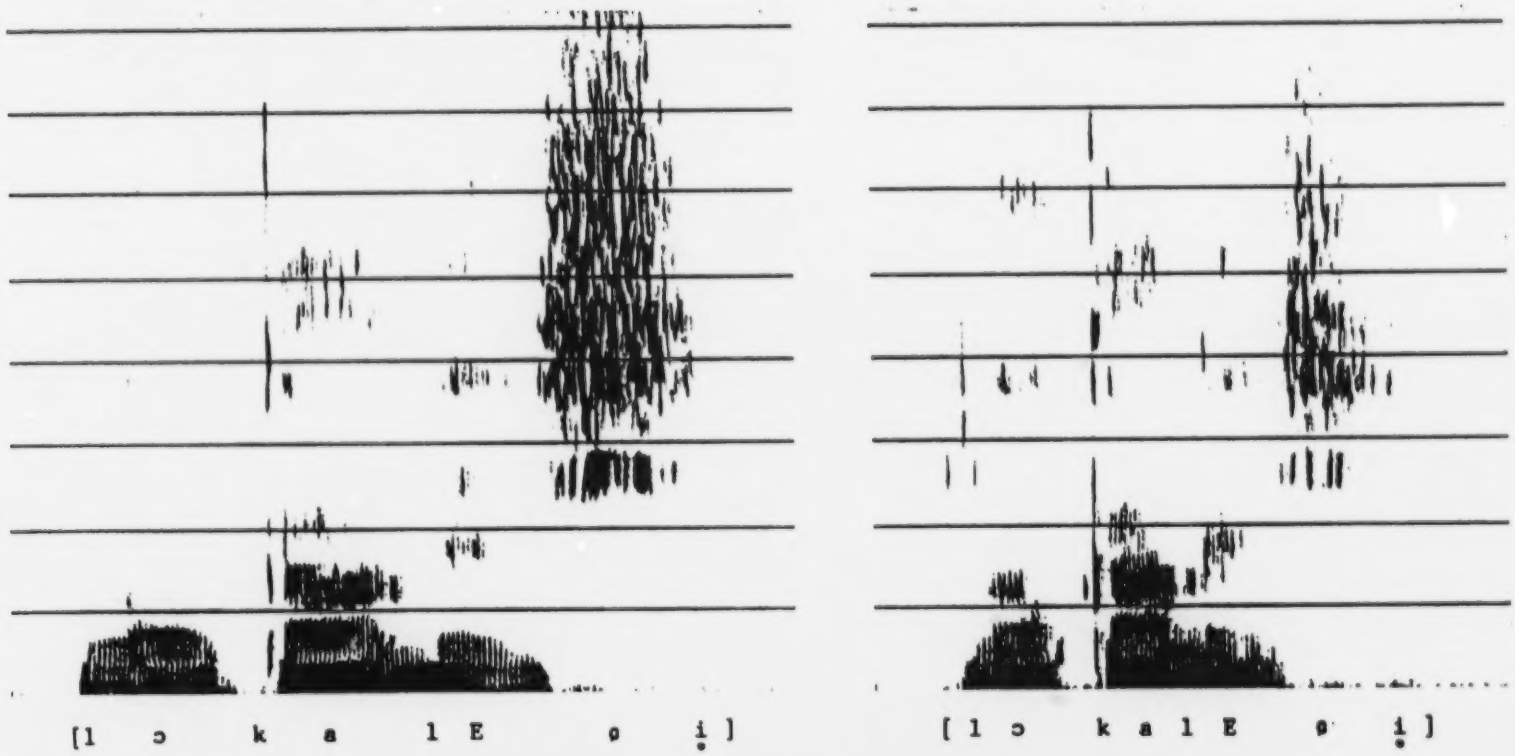

Fig.(11) Spectrograms of the quadrisyllabic compound [lɔkalEɕi̯][LHML]" kind of boastful" uttered at normal (left) and fast (right) speech rates.

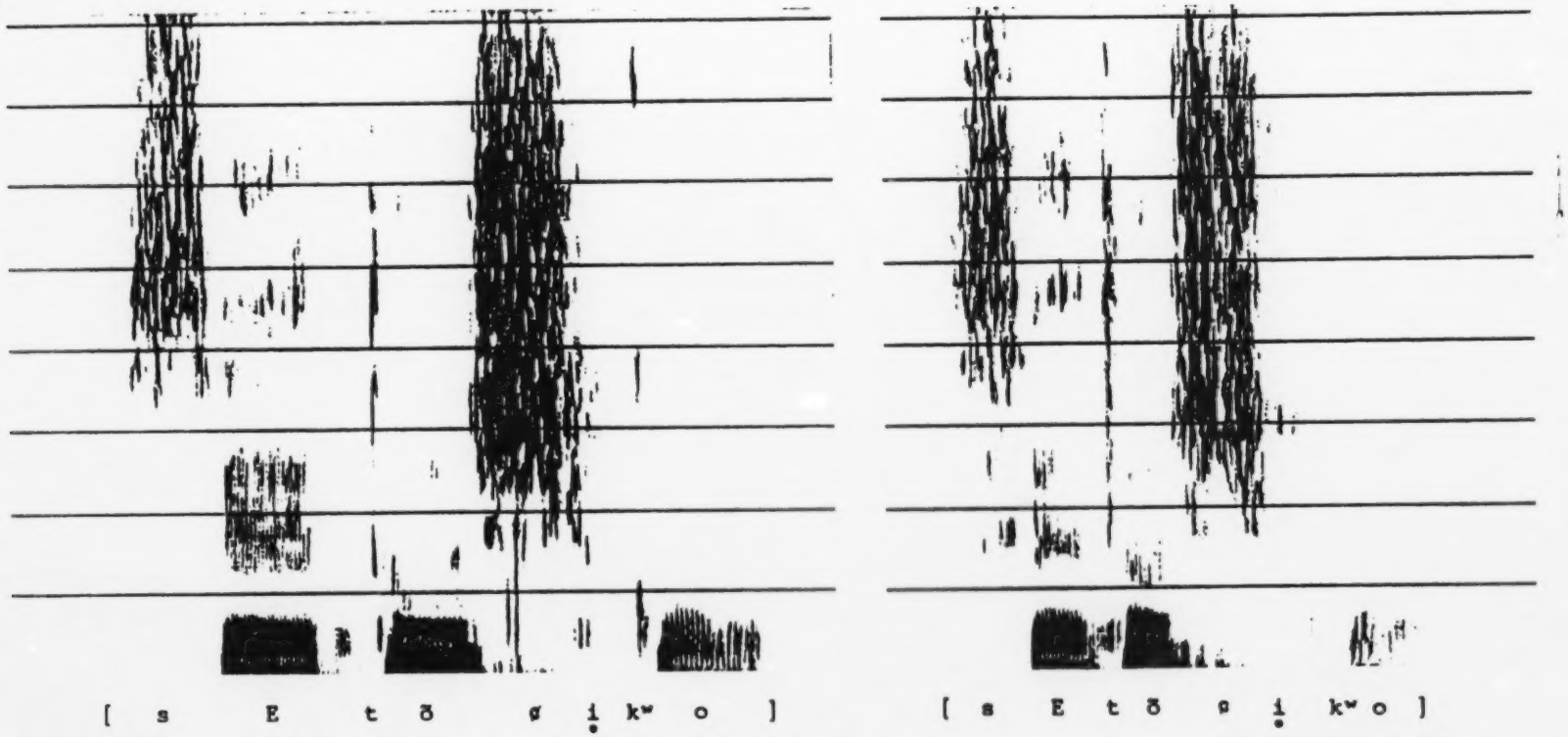

Fig.(12) Spectrograms of the trisyllabic compound [sEtɔ̃ɒi̤kʷo][HML^L]"Shandong watermelons" uttered at normal (left) and fast (right) speech rates.

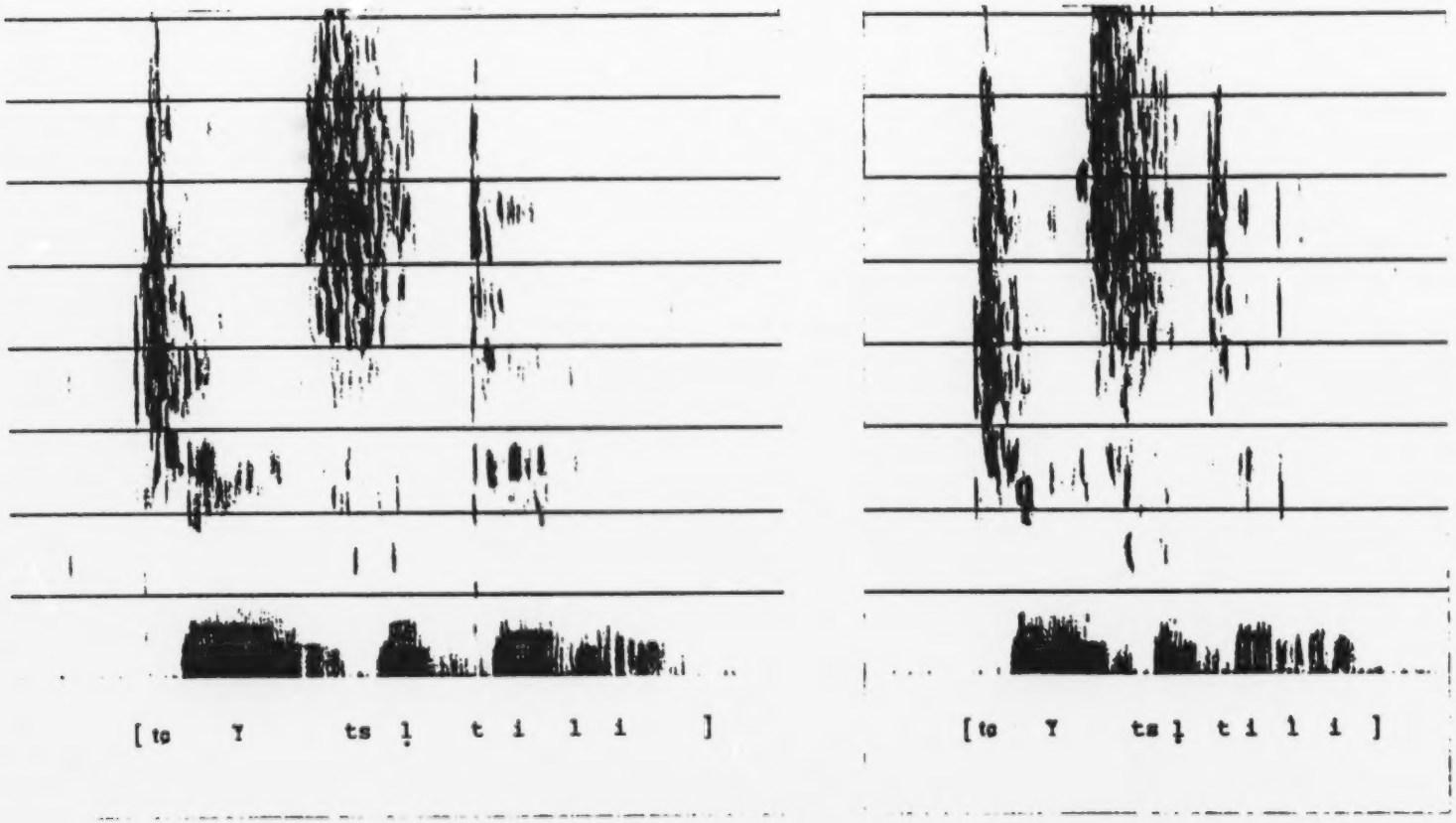

Fig.(13) Spectrograms of the quadrisyllabic compound [tɑʔtsl̥tili][HML^L] "in a gold shop" uttered at normal (left) and fast (right) speech rates.

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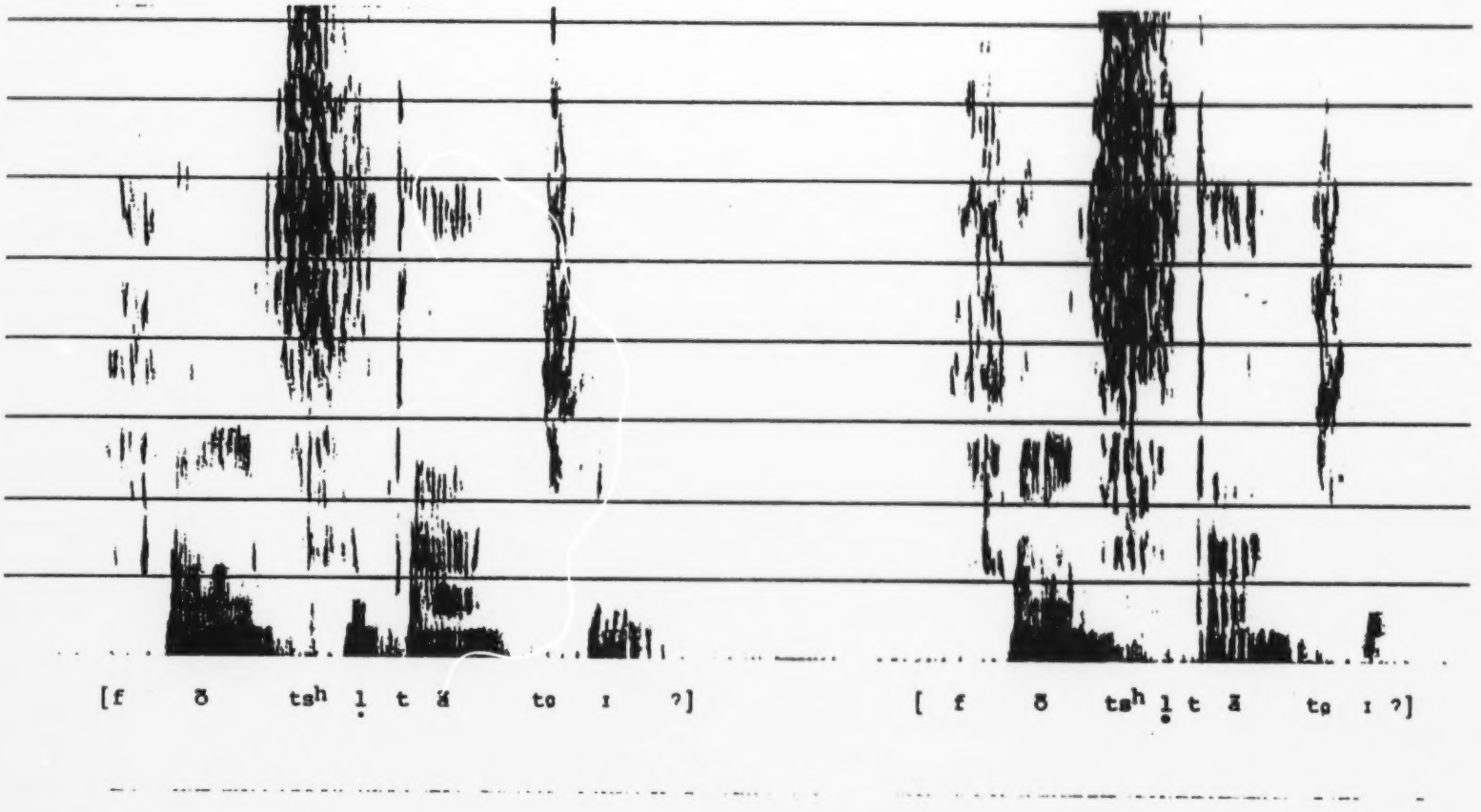

Fig.(14) Spectrograms of the quadrisyllabic compound [fɔ̃tsʰl̥tãtɑɪʔ][HML^L]"satirical attack" uttered at normal (left) and fast (right) speech rates.

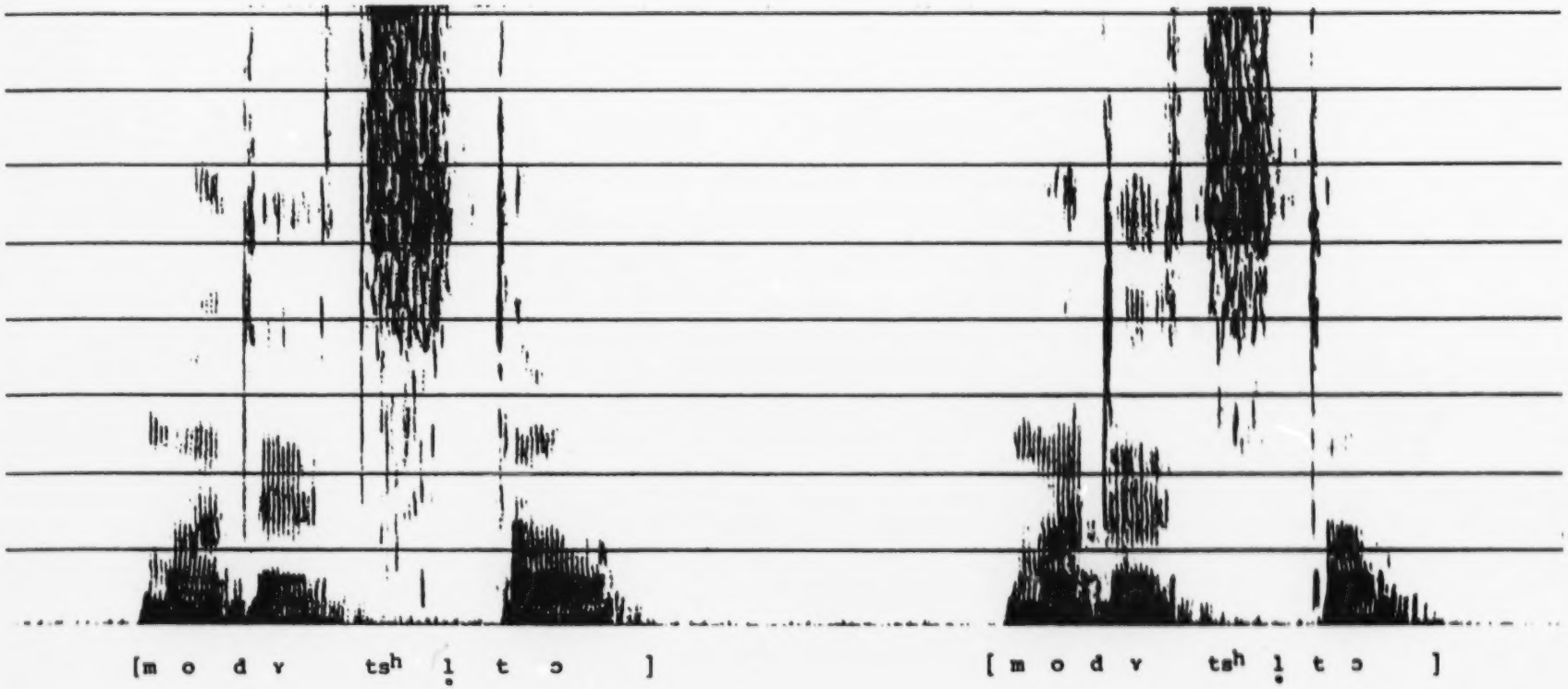

Fig.(15) Spectrograms of the quadrisyllabic compound [modvtsʰl̥tɔ][LLLM]"a wooden bayonet" uttered at normal (left) and fast (right) speech rates.

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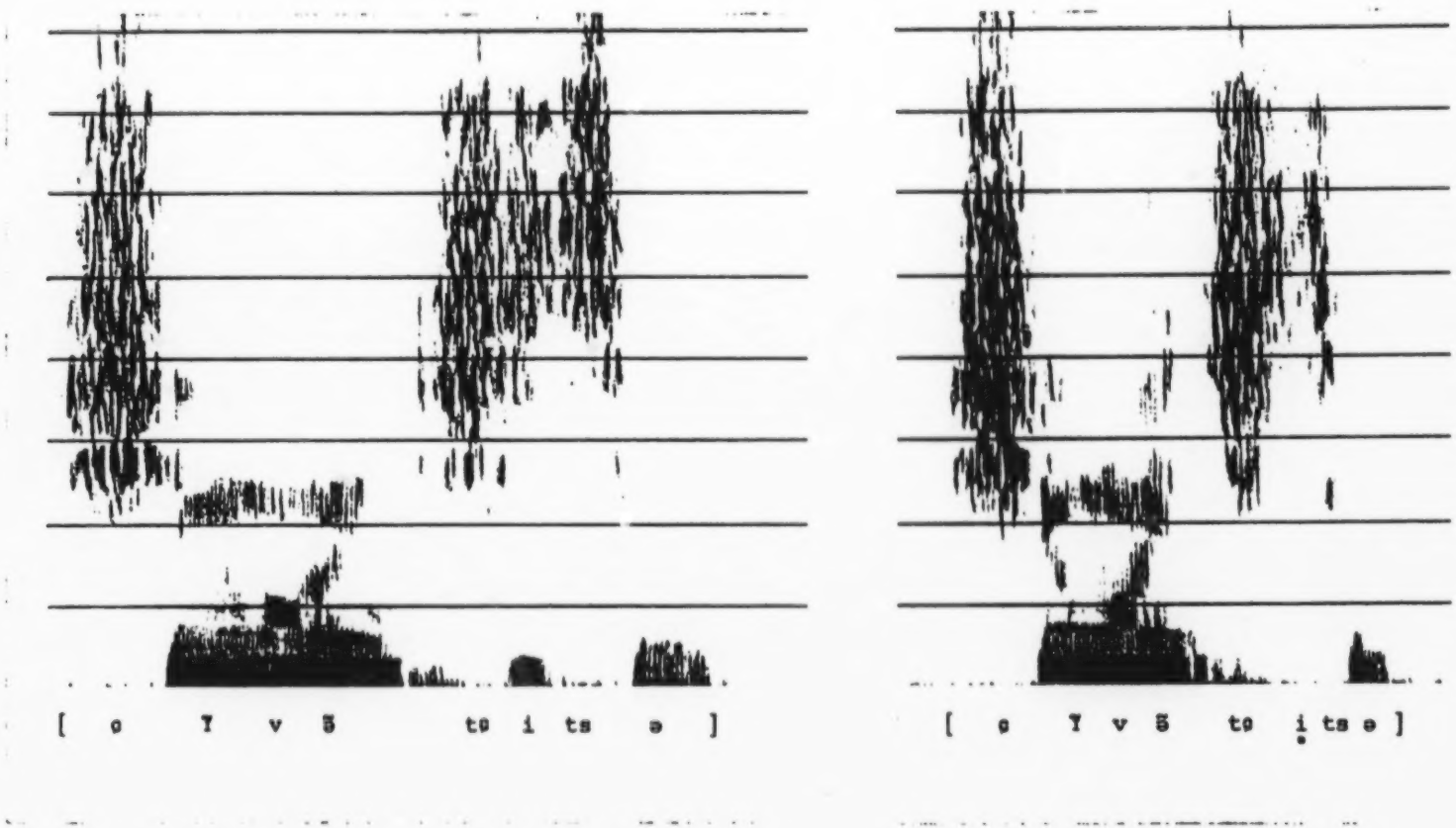

Fig.(16) Spectrograms of the quadrisyllabic compound [øʔvɔ̃tɕitsə][HML^L]"news reporters" uttered at normal (left) and fast (right) speech rates.

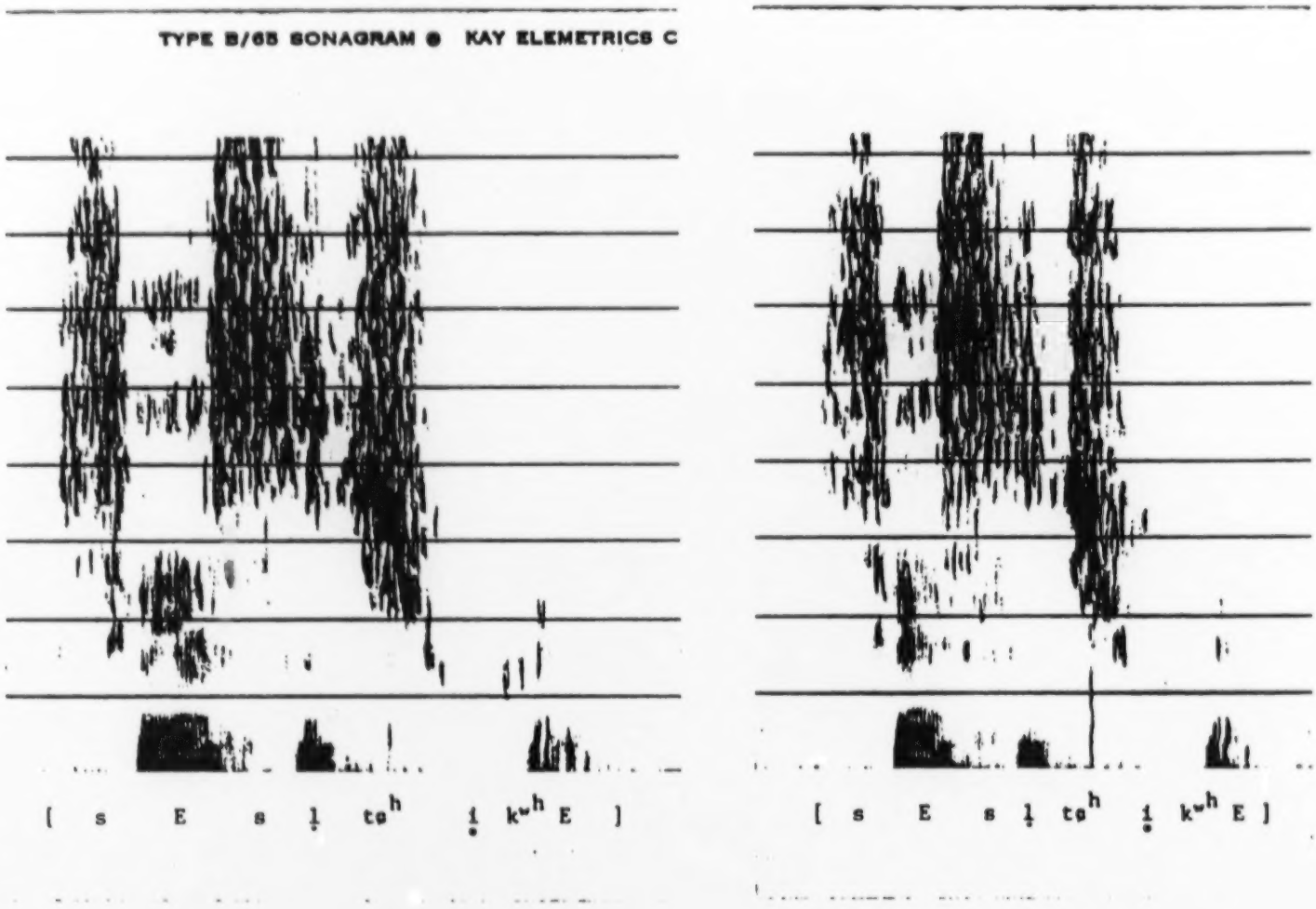

Fig.(17) Spectrograms of the quadrisyllabic compound [sEsɻ̥tɕʰikʷʰE][HML^L]"some three to four thousand dollars" uttered at normal (left) and fast (right) speech rates. of speech.

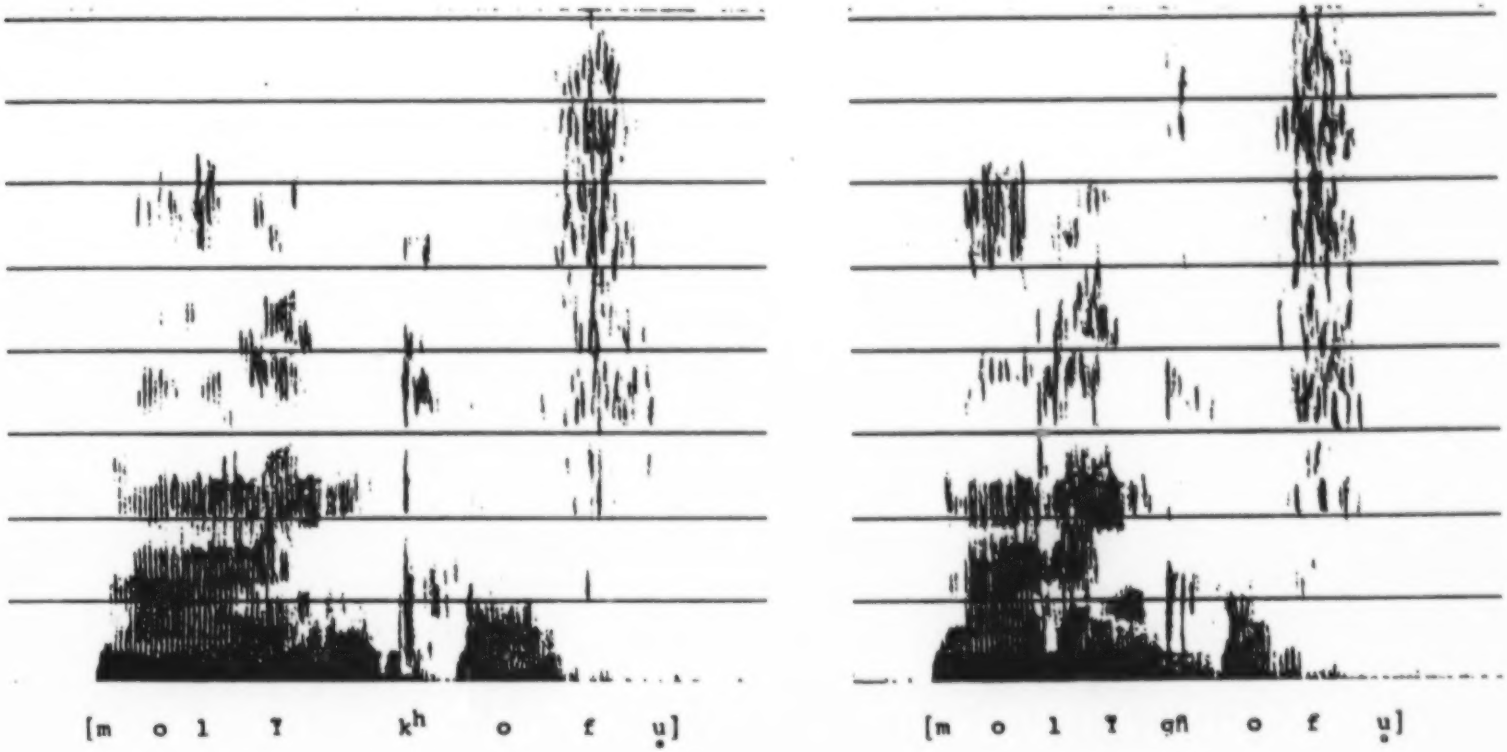

Fig.(18) Spectrograms of the quadrisyllabic compound [molʔkʰufu̥][ᴍᴎᴍL]"Malinkov(a Russian name)" uttered at normal (left) and fast (right) speech rates.

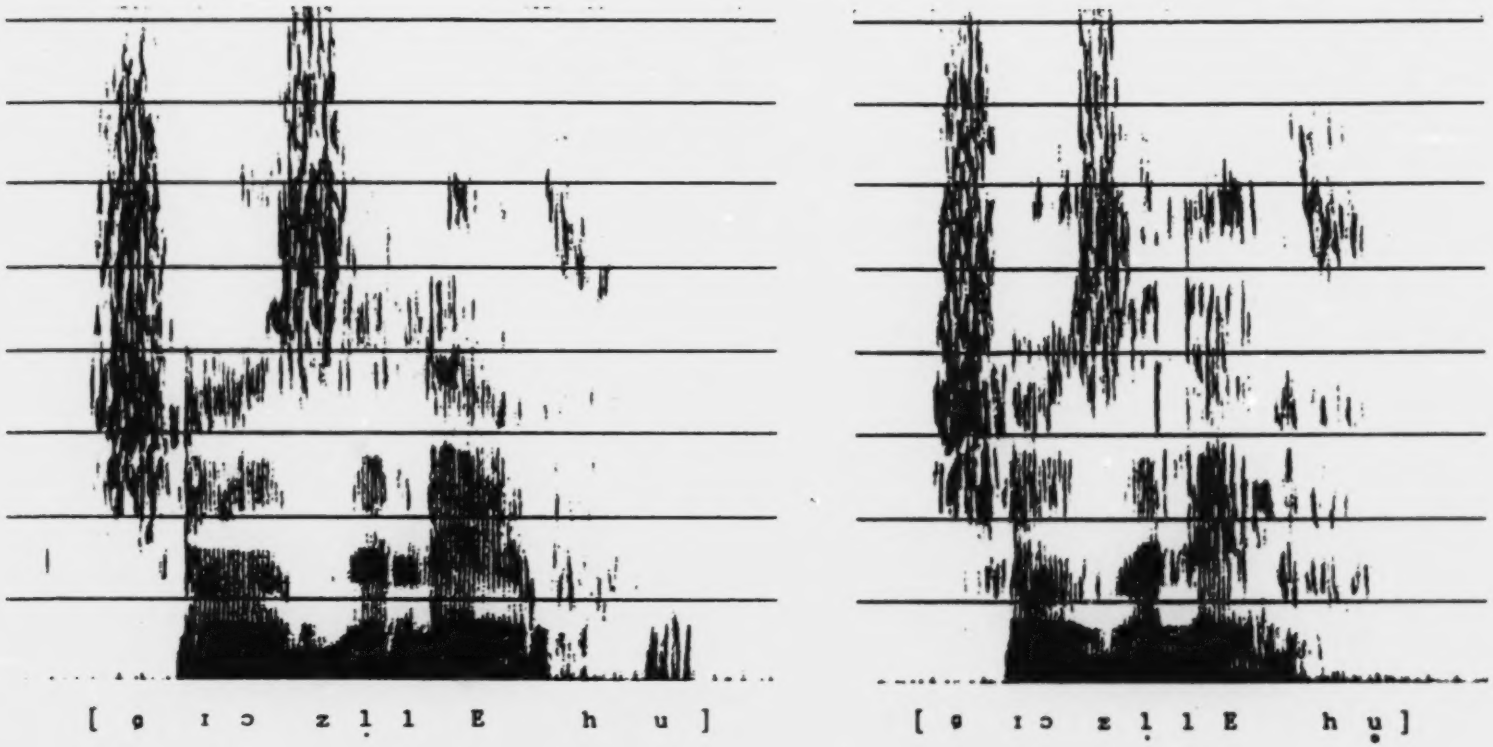

Fig.(19) Spectrograms of the quadrisyllabic compound [øɪɔzllEhu][MHML]"small matches" uttered at normal (left) and fast (right) speech rates.

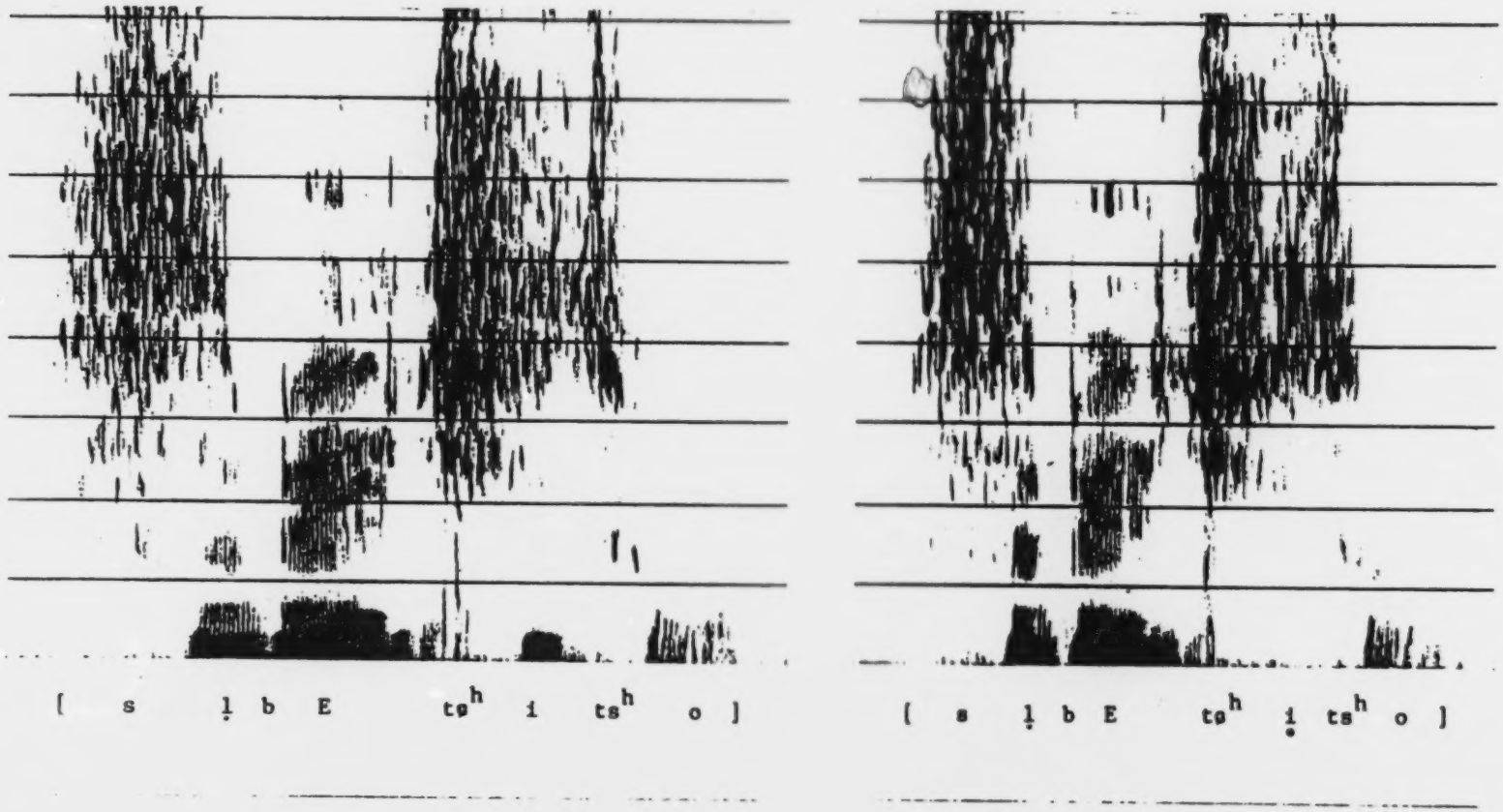

Fig.(20) Spectrograms of the quadrisyllabic compound [slbEtɕʰitsʰo][LHML]"a private car" uttered at normal (left) and fast (right) speech rates.